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# **Technical Evaluation for the Disposal of Mixed Waste at Low-Level Radioactive Waste Disposal Facilities**

Technical Background Document  
Draft

Prepared by:

Research Triangle Institute  
3040 Cornwallis Dr.  
Research Triangle Park, NC

Prepared for:

U.S. Environmental Protection Agency  
Office of Solid Waste  
Washington, DC

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## Executive Summary

“Mixed waste” is a term coined in the 1980s to describe waste composed of both hazardous waste and source, special nuclear, or byproduct material subject to the Atomic Energy Act (AEA) of 1954. Mixed waste may be generated from several types of operations, including nuclear-powered utilities, fuel cycle facilities, pharmaceutical companies, medical and research laboratories, and universities and academic institutions.

The hazardous waste component of mixed waste is regulated under Subtitle C of the Resource Conservation and Recovery Act (RCRA) based on a congressional committee’s consensus that both the Nuclear Regulatory Commission (NRC) and the U.S. Environmental Protection Agency (EPA) should regulate mixed waste. As a result, EPA interpreted its RCRA enforcement charge to include any waste containing hazardous chemicals, even those wastes that were regulated for their radioactivity under AEA.

Utilities, nonutilities (e.g., pharmaceuticals, academia), and the U.S. Department of Energy (DOE) have questioned the need for dual regulatory authority over mixed waste. These stakeholders contend that waste management facilities licensed by the NRC protect human health and the environment against not only radiation hazards, but also chemical hazards. That is, NRC-regulated land disposal facilities designed to protect human health from exposure to radionuclides above NRC regulatory levels would also protect human health and the environment from exposure to hazardous

waste chemicals constituents. Therefore, in 1997, EPA committed to the Edison Electric Institute (EEI), as part of the Hazardous Waste Identification Rule (HWIR) settlement agreement, to evaluate the possible exemption of the hazardous portion of low-level mixed waste (LLMW) from RCRA Subtitle C disposal requirements. The scope of this commitment and, in turn, the context of this Technical Background Document, is the disposal of mixed waste at commercial, low-level radioactive waste (LLRW) disposal facilities.

### Technical Approach

EPA and state agencies for radioactive and hazardous waste management discussed how to compare the benefits and areas of uncertainty of the NRC and EPA regulatory authorities. One early approach entailed multimedia, multipathway exposure assessment modeling of EPA and NRC facilities (and uncertainty analysis). However, it was later decided that a second, less quantitative analytical approach was appropriate for a conditional exemption that EPA was considering for disposal of LLMW. This selected approach avoided issues related to intensive data needs and modeling approach (site-specific vs. national). It was decided that this approach would provide a sufficient level of information to allow EPA to ascertain what, if any, conditions exist under which a RCRA exemption could ensure that NRC-regulated mixed waste management could sufficiently protect human health and the environment.

To evaluate the potential for a RCRA exemption, EPA believes that it is important to ascertain the level of protection achieved at a land disposal facility, be it NRC regulated or EPA regulated. That is because land disposal is the final destination in the “cradle-to-grave” management of mixed waste. Aspects of land disposal, such as natural hydrogeologic and climatologic settings, along with design engineering, groundwater monitoring, NRC sites’ operating history, and postclosure maintenance, are among the most sensitive measures for landfill performance.

This Technical Background Document examines sensitive measures of landfill performance by evaluating the regulatory authorities of NRC and EPA over mixed waste disposal from five perspectives:

- # **RCRA Land Disposal Restrictions** (LDR) treatment performance in the context of meeting maximum contaminant level (MCL) groundwater protection criteria.
- # **Engineering features** of NRC- and EPA-regulated land disposal facilities, particularly landfill cover designs, containerization, and liner performance.
- # **Groundwater monitoring and operating performance history of commercial NRC LLRW disposal facilities**, including layout of site groundwater monitoring wells and presentation of sites’ performance from a groundwater quality perspective.
- # **Physical and hydrogeologic characteristics** of NRC-regulated, commercial LLRW disposal facilities compared to commercial, EPA-regulated hazardous waste landfills.

- # **Site selection requirements and postclosure or institutional controls** practiced at NRC and EPA facilities to protect human health and the environment after landfills are closed to further disposal.

These five perspectives were selected because they represent the five sensitive indicators of the level of protection NRC and EPA statutory authorities provide. By examining the **physical and hydrogeologic characteristics** of existing sites, EPA can assess the protection that the NRC and EPA land disposal siting criteria provide. It is also important to know **operating histories** and **groundwater monitoring** practices at NRC-licensed LLRW disposal sites to evaluate the real-world performance of the NRC groundwater monitoring program. NRC and EPA **engineering** philosophies differ for land disposal. Predisposal treatment, landfill designs, and the landfill cover designs are representative of areas where engineering philosophies differ. Therefore, EPA chose to compare the performance of the potential roles that each regulatory program’s engineering system plays in minimizing the threat of groundwater contamination. The performance of NRC high-integrity containers and RCRA liners was also selected as an integral point of comparison. These two engineering structures are inherent to these regulatory programs and seem to address a similar need. **Site selection requirements** and **EPA postclosure and NRC institutional controls** were compared for a variety of reasons. For example, the legacy of certain radionuclides is much longer-lived (over 10,000 years) than that of nonmetal, hazardous chemicals. In addition, the determination that EPA and NRC landfills perform equally during their active lives could be augmented by a comparison of how well each regulatory approach protects human health and the environment after closure. For example, a major goal of both engineered

systems and operating practices is to prevent the generation and subsequent migration of contaminated leachate from the landfill. This study compares how the two regulatory programs seek to attain this performance goal.

The findings in these five study areas are summarized in the following paragraphs.

### **Protection of Groundwater: NRC Monitoring and LLRW Disposal Sites' Operating History**

EPA regulations explicitly require protection of groundwater. Although the NRC does not specifically require protection of groundwater, NRC regulations and subsequent licensing requirements for LLRW disposal facilities require that groundwater be monitored and radionuclide releases be mitigated. Discussions with states and disposal facilities indicate that some releases of radionuclides have occurred at the facilities; however, these releases were below the regulatory limits for drinking water known as MCLs and these releases occurred at disposal units constructed before the promulgation of NRC regulations (10 CFR Part 61). Before 1986, two commercial LLRW disposal facilities (Barnwell, SC, and Richland, WA) did receive mixed waste for disposal. To date, no chemical releases exceeding their MCLs have been found in groundwater monitoring samples from these facilities.

A comparison of Safe Drinking Water Act MCLs to RCRA LDR Universal Treatment Standards (UTSs) was made to determine if UTSs protect human health to a level comparable to MCLs. The results of the analysis led EPA to conclude that the proposed mixed waste exemption—conditioned on compliance with LDR treatment standards—can attain sufficient protection of human health for RCRA waste constituents in groundwater that also have

MCLs. The screening level analysis indicated that nine organic chemicals and three metals may have exceedances of MCLs following LDR treatment and allowance for dilution and attenuation. However, only one chemical was reported as existing in the utility industry's waste database—1,1,2-trichloroethane. Where the potential for groundwater contamination may exist, the volume of trichloroethane is relatively small when factored into total landfill capacity.

### **Predictive Comparison of Cover Design Performance at Commercial NRC-Regulated Landfills and an EPA-Regulated RCRA Subtitle C Landfill**

The purpose of this analysis was to compare the performance of landfill cover designs for an EPA-regulated Subtitle C landfill and commercial NRC LLRW disposal facilities. The comparison was based on an estimate of permeabilities through landfill covers. Site-specific data were used where available, and engineering judgment was used to assume reasonable values for properties where data were unavailable.

Results ranked the eight cover designs based on volume of the equivalent hydraulic conductivities. Performance ranged from  $9.41 \times 10^{-10}$  to  $8.44 \times 10^{-7}$  cm/s, with the EPA cover design falling within the range at  $2.3 \times 10^{-7}$  cm/s.

### **NRC-Regulated Waste Containerization Technologies and EPA-Regulated Liner Systems**

This preliminary comparison was conducted through a review of performance assessment reports for NRC-regulated facilities; pertinent EPA and NRC regulations; readily available vendor information; and literature available on-line pertaining to LLRW and LLMW disposal and container use at

commercial facilities, waste stabilization technologies, and material corrosion. Little information was found that directly compares the performance of containers typically used by EPA-regulated disposal facilities to those used by NRC-regulated facilities. Therefore, the approach selected for this investigation was to compare life expectancy of the NRC high-integrity containers (HICs) to the more traditional containers used at EPA and NRC facilities.

The comparison revealed that the life expectancy of HICs (such as concrete vaults) exceeds that of traditional 55-gallon carbon steel containers required by EPA. However, an examination of RCRA geosynthetic membranes (which facilities use in RCRA liner systems) found the life expectancy to be comparable to HICs. The information is summarized in Table ES-1.

### Comparison of Physical and Hydrogeologic Characteristics of Selected NRC-Regulated Commercial Landfills and EPA-Regulated Subtitle C Commercial Landfills

This study was derived from a groundwater sensitivity analysis that compared receptor distances and climatic, soil hydrogeologic, and unit characteristics that can impact health risks through the ground-water pathway for the different types of land disposal units. EPA selected 19 EPA-regulated, RCRA Subtitle C commercial land disposal facilities and five commercial NRC-regulated land disposal facilities for this comparison. Site-specific documentation was used whenever possible. If unavailable, national data sources and semiautomated data collection methods were used to obtain information. Based on the information

**Table ES-1. Performance Information on Traditional Containers,<sup>a</sup> High-Integrity Containers, and RCRA Liner Systems**

Scenario	Design Life (years)	Predicted Actual Life (years)	Maximum Life (years)
<b>Baseline</b> - carbon steel drum	30 (EPA-required postclosure care period)	13-166 (potential corrosion rate of carbon steel)	> 13-166 (assuming steel is coated/lined)
<b>Concrete vault</b>	300 (NRC <i>Technical Position</i> specifications)	1,400 (estimated time that vaults are to remain intact - SRS) <sup>b</sup>	1,400-3,100 (assumed collapse of vault roof - SRS) <sup>b</sup>
<b>Polyethylene macroencapsulation</b>	300 (NRC <i>Technical Position</i> specifications)	300 (testing for SC Dept. of Health)	>300 years (in an arid, NRC-regulated facility)
<b>RCRA liner systems</b>	30 (EPA-required postclosure care period)	70-80 (Kroener, 1999)	270-1,000 (Kroener, 1999)

<sup>a</sup> EPA regulations do not require disposal of hazardous waste in containers so long as the waste is not a liquid.

<sup>b</sup> Although the Savannah River Site (SRS) is not an NRC-licensed facility, its studies provide valuable performance analyses of the concrete vault technology.

collected, several general conclusions were drawn about the physical and hydrogeologic comparability of the commercial EPA-regulated and NRC-regulated landfills:

- # For the physical and hydrogeologic conditions evaluated, the commercial NRC-regulated landfill sites are sufficiently protective. Both Subtitle C and NRC facilities tend to be sited, on average, in fairly protective locations (based on distance to receptors, climate, and soils).
- # The eight western EPA-regulated Subtitle C land disposal facilities are very similar to the NRC-regulated facilities, with some Subtitle C landfills being collocated with NRC-regulated landfills. The generally isolated locations of these landfills result in long distances to receptor wells.
- # Many of the western Subtitle C and NRC disposal facilities are in arid climates. This results in generally deeper water tables (i.e., thick unsaturated zones beneath landfills) and low recharge and infiltration rates. For several of the eastern Subtitle C facilities, low-permeability soils limit recharge and infiltration rates.

### **Comparison of NRC and EPA Siting Requirements**

NRC and EPA each address site selection through requirements that range from consideration of sensitive environments (e.g., floodplains) to human health effects of land disposal activities. Land disposal operations have potentially far-reaching and challenging-to-characterize impacts. Siting-related regulations in the NRC and EPA programs were identified, evaluated, and compared. Resources used included 10 CFR Part 61 and 40 CFR Parts 264 and 270, NRC licensing documents (where available), and senior staff knowledge and experience with the two programs. Subject areas evaluated included:

- # Development of disposal site selection criteria
- # Capability of site to be characterized, analyzed, modeled, and monitored (with emphasis on groundwater monitoring)
- # Protection of disposal unit from groundwater intrusion and protection of surface water via groundwater discharge
- # Role of liquids in landfills – both waste liquids and leachate generation
- # Wetlands
- # 100-year floodplains
- # Proximity to populations and development
- # Proximity to natural resources.

Each topic compares the benefits and areas of uncertainty of the relevant NRC and EPA systems. For example, a comparison of groundwater monitoring requirements found that the NRC's system – while targeting protection of human health from exposure to radionuclides above NRC regulatory levels – also requires monitoring in the disposal unit's buffer zone. This monitoring is intended to (1) detect releases, and (2) enable implementation of mitigative measures in the buffer zone before further migrations on the facility's property.

A second example compared EPA and NRC regulations that target minimizing the generation of contaminated leachate or free liquids. Both regulatory programs discourage or prohibit the disposal of liquids in landfills. Both programs also require covers designed to minimize or prevent the percolation of rainfall through covers.

## Comparison of EPA Postclosure Care Regulations to NRC Institutional Controls

The NRC uses the term “institutional control” to refer to the period that follows land disposal site closure and during which periodic maintenance and monitoring activities are conducted. The facility is assumed to be closed, stabilized, and maintained but is still part of the parent facility. The comparable EPA activity is referred to as the postclosure period during which monitoring and maintenance occur for 30 years after the land disposal unit’s closure.

The NRC and EPA systems were compared for the following subject areas believed to potentially fall within the scope of institutional control:

- # Ownership
- # Buffers
- # Postclosure care
- # Public records of the closed site.

## Conclusion

It is believed that NRC requirements can provide sufficient protection given—

- # The condition that mixed wastes must comply with RCRA LDRs prior to disposal
- # The findings drawn from the policy and technical information collected and analyzed in this document.

On balance, EPA believes that RCRA landfills provide more or enhanced protection from releases to groundwater when compared to NRC-regulated landfills. This is because EPA requires double liners and double leachate collection systems, potentially thicker clay caps, geomembranes in the caps, and other requirements not provided for NRC-regulated landfills. However, EPA believes that LDR treatment requirements, in combination with NRC requirements, can compensate for deficiencies and make NRC-regulated landfills sufficiently protective of human health and the environment.

## 2.0 Background

The AEA of 1954, as amended, grants the NRC responsibility for the licensing and regulating of nuclear facilities and materials. In 1983, the NRC promulgated licensing requirements for the land disposal of radioactive waste. The NRC chose to make these new regulations a combination of performance-based and prescriptive technology-based requirements. The intent was to allow flexibility in how land disposal designs met four general performance objectives (U.S. Office of Technology Assessment, 1989):

1. Protection for occupationally exposed workers and the public during the operation of the site
2. Protection of the environment over the long term
3. Protection for any intruder who might inadvertently make contact with the waste material
4. Assurance that the site will maintain its stability for several hundred years.

In 1976, Congress enacted RCRA, authorizing EPA to develop a regulatory program to manage chemically hazardous waste from cradle to grave. EPA was also authorized to identify those wastes deemed to be hazardous to human health and the environment. EPA's first major promulgation package of generation, transportation, treatment, storage, and disposal regulations was published in May 1980. Congress reauthorized RCRA in 1984 as the Hazardous and Solid Waste Amendments (HSWA). These amendments elaborated on and expanded EPA's authority to restrict land disposal of hazardous wastes without prior treatment sufficient to significantly reduce the waste's hazard in case of unintentional release to the environment from the disposal unit.

Following questions raised about the applicability of EPA regulations to LLRW management operations and subsequent congressional hearings, a congressional committee reached consensus that both the NRC and EPA should regulate mixed waste. On July 3, 1986 (51 FR 24504), EPA published clarification that RCRA applies to wastes that contain two types of components: a hazardous waste component that is regulated under Subtitle C of RCRA and a radioactive component consisting of source, special nuclear, or byproduct material that is regulated by the NRC. EPA interpreted its RCRA enforcement charge to include any waste containing hazardous chemicals, even those wastes that were already regulated for their radioactivity under the AEA. The definition of mixed waste was added to the RCRA statute by the Federal Facility Compliance Act (FFCA) of 1992. Thus, mixed waste is jointly regulated under both RCRA and the AEA. RCRA regulates the hazardous waste portion of the waste as

any other hazardous waste, while the AEA regulates the RCRA-exempt radioactive portion (52 FR 15939, May 1, 1987).

Mixed waste, regardless of its type of radioactive element, is hazardous waste and, consequently, is subject to RCRA hazardous waste regulations, including the LDRs. Treatment standards for hazardous wastes are found in Section 268.40 of the RCRA regulations. In some cases, special treatment standards are listed for mixed wastes, such as for radioactive lead solids (D008) and elemental mercury contaminated with radioactive materials (D009). When no special standards are listed, the normal treatment standards for the particular waste code apply (55 FR 22644, June 1, 1990).

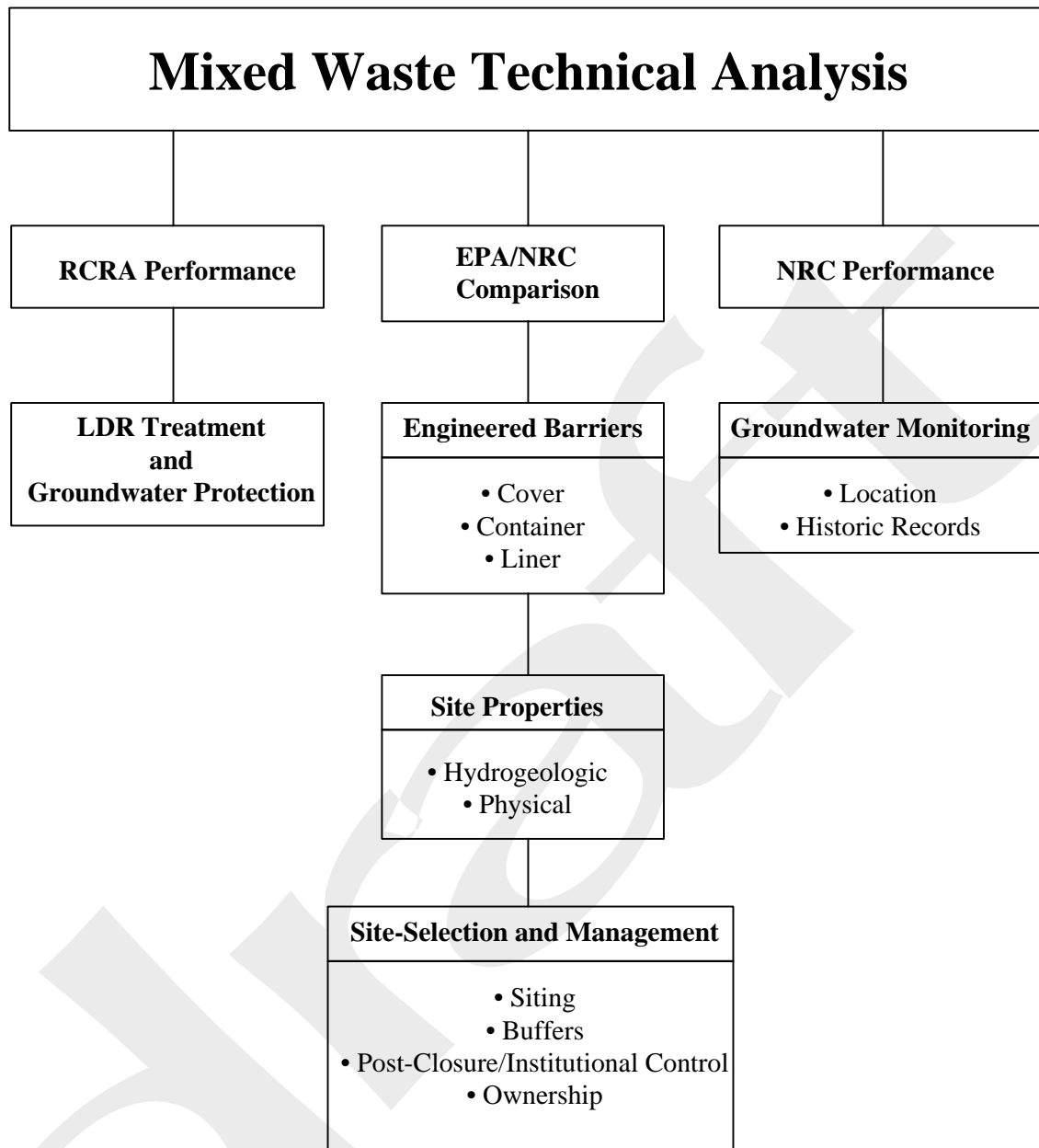
Since 1986, utilities, nonutilities (e.g., pharmaceuticals, academia), and the U.S. DOE have questioned the need for dual regulatory authority over mixed waste. In 1997, EPA committed to the Electrical Engineering Institute (EEI) and other parties, as part of the HWIR settlement (*ETC v. Browner*, CIV No. 94-2119 [D.D.C.]), to evaluate the possible exemption of the hazardous portion of low-level mixed waste (LLMW) from RCRA Subtitle C disposal requirements. The scope of this commitment, and, in turn, the context of this Technical Background Document, is the disposal of mixed waste at commercial, low-level radioactive waste disposal facilities.

## 3.0 Technical Approach

EPA committed to EEI to study the need for dual statutory authority by evaluating the possible exemption of the hazardous portion of LLMW from RCRA Subtitle C disposal requirements. EPA and state radioactive and hazardous waste management agencies discussed how to compare the benefits and areas of uncertainty of these two statutory authorities. One early approach entailed multimedia, multipathway exposure assessment modeling of EPA-regulated and NRC facilities (and uncertainty analysis). However, it was decided that a second, less quantitative, analytical approach was less likely to precipitate questions about the uncertainty of risk estimates and was also more timely and more appropriate. The approach reflected states' desires to compare performance indicators (e.g., locational settings, engineering designs, and security/integrity of closed facilities' property) in a semi-quantitative or qualitative fashion. They concurred that this approach would achieve the desired assurance to ascertain the level of protection to human health and the environment each authority attains. Figure 3-1 illustrates how this Technical Background Document examines the dual statutory authorities of the AEA and RCRA over disposal of LLMW from five perspectives:

- # **RCRA Land Disposal Restrictions (LDR)** treatment performance in the context of meeting MCL groundwater protection criteria.
- # **Engineering features** of NRC- and EPA-regulated land disposal facilities, particularly landfill cover designs, containerization, and liner performance.
- # **Groundwater monitoring and operating performance history**, including layout of sites' groundwater monitoring wells and presentation of sites' performance from a groundwater quality perspective.
- # **Physical and hydrogeologic characteristics** of NRC-regulated, commercial LLRW disposal facilities compared to commercial, EPA-regulated hazardous waste landfills.
- # **Site selection requirements and postclosure or institutional controls** practiced at NRC and EPA facilities to protect human health and the environment after landfills are closed to further disposal.

These five perspectives were selected because they represent the five most sensitive indicators of the level of protection each statutory authority provides. By examining the two regulatory programs' **physical and hydrogeologic characteristics** of existing sites, EPA can



**Figure 3-1. Technical approach to examine NRC-regulated and EPA-regulated systems.**

assess the present-day level of natural detention and, in turn, the protection that the NRC and EPA land disposal siting criteria provide. It is also important to know **operating histories** and **groundwater monitoring** practices at NRC-licensed LLRW disposal sites to evaluate the real world performance of the NRC groundwater monitoring program. The NRC and EPA **engineering** philosophies differ for land disposal. Predisposal treatment, landfill designs, and landfill cover designs at these facilities are representative of these different philosophies. Therefore, EPA chose to compare the performance of the potential roles that each regulatory

program's engineering system plays in minimizing the threat of groundwater contamination. The performance of NRC HICs and RCRA liners were also selected as integral points of comparison. **Site selection requirements and EPA postclosure and NRC institutional controls** were compared because, for example, the legacy of certain radionuclides is much longer-lived (over 10,000 years) than that of hazardous chemicals. In addition, if it were determined that both authorities' landfills performed equally well during their active lives, the question of how well each authority would protect human health and the environment after closure was asked.

Details on how the study areas were planned and researched are provided in Sections 4 through 7. To summarize:

- # **LDR-related groundwater levels** and their comparability to drinking water standards were predicted by applying dilution and attenuation rate assumptions to waste compliant with LDR UTSSs. The likelihood of unsafe contaminant levels resulting in groundwater from utilities waste was then determined by referencing industry waste generating data.
- # **Engineering performance** assessments of landfill covers were conducted by obtaining site-specific cover design criteria from host state licensing agencies. The overall conductivity of each site's cover was estimated, and cover designs were ranked based on the estimated volume of rainfall penetrating the cover thickness in 1 year. An engineering performance assessment of NRC vs. EPA-regulated containers was performed by reviewing design criteria for HICs, searching the Internet for research studies on containerization technologies, and reviewing license applications where HICs are proposed for land disposal. The life expectancy of EPA-regulated landfill liner systems was examined through a review of recent research findings on geosynthetic membranes.
- # NRC sites' **operating histories and groundwater monitoring practices** were profiled by reviewing relevant information on licensed sites provided by state licensing authorities.
- # **Physical settings and hydrogeologic data** were compiled by first selecting commercial NRC-regulated land disposal facilities and commercial EPA-regulated hazardous waste land disposal facilities. EPA focused on commercial facilities because they represent land disposal capacity available, in theory, to all LLMW generators. Also, EPA did not consider DOE's on-site, self-regulated disposal facilities as part of this analysis. Parameters representative of physical settings, hydrogeologic factors, and climatologic parameters were selected based on sensitivity to landfill performance and availability in the literature or via the Internet.
- # **Site selection requirements** were identified under 10 CFR 61 (NRC) and 40 CFR 260-270 (EPA). The requirements were examined to identify (1) where both systems addressed a site selection topic, and (2) where only one system addressed a topic. Once such components of the requirements were identified, the benefits

and areas of uncertainty of each topical component were determined based on regulatory history, scientific judgment, and relevant significance in their respective programs. **Postclosure and institutional controls** were identified in 40 CFR 260-270 and 10 CFR 61, respectively. As with the physical settings evaluation described above, the requirements were examined to identify (1) where both systems addressed relevant topics, and (2) where only one system addressed a topic. Once such topical components of the requirements were identified, the benefits and limitations of each topical component were determined based on regulatory history, scientific judgment, and relevant significance or importance in their respective programs.

## 4.0 Treatment and Engineered Structures Performance

The RCRA program has a strong preference for treatment in conjunction with disposal of hazardous waste. This approach promotes a measure of protection even prior to the placement of the waste in the disposal unit. This action compliments the protectiveness of the RCRA landfill cover and liner by rendering the waste less hazardous through reduction of toxicity and mobility of hazardous waste constituents. This approach is carried into EPA's regulatory approach for the disposal of mixed waste. EPA's perspective is that if the hazard of the material can be reduced before it goes into the LLRW disposal facility, then less stress is placed on the engineered structures and the groundwater monitoring system. This treatment strategy would tend to minimize any difference between EPA and NRC engineered structures and groundwater monitoring programs. Differences do exist between the two regulatory authorities disposal specifications. While these differences exist, the analysis looks at the protectiveness achieved by the overall system, not just what a container or liner/leachate collection system achieves.

This section presents analyses of two performance measures selected to assess the ability of NRC-regulated landfills to manage mixed waste at a sufficient level of protection:

- # The efficacy of LDR Universal Treatment Standards to protect groundwater underlying NRC-regulated landfills
- # The performance of NRC and EPA-regulated engineered components of landfills, i.e., covers, high integrity containers, and liner systems.

This two-fold analysis is intended to address two stages in mixed waste management systems where disposers will be able to reduce and/or minimize the potential for groundwater contamination from mixed waste.

### 4.1 Application of RCRA Universal Treatment Standards to Mixed Waste Chemical Constituents: Are UTS Values Comparable to Drinking Water Standards?

This section compares Safe Drinking Water Act Maximum Contaminant Limits (MCLs) (40 CFR 141.61-141.62) to RCRA UTSs (40 CFR 268.48) for both MCL-listed and UTS-listed constituents. The purpose of this analysis is to use the groundwater protection metric of MCL and compare it to what is achievable under the auspices of the RCRA hazardous waste UTS treatment requirements. This analysis is developed as a screening exercise to gauge what protection is afforded by waste treatment prior to disposal. The ratio of these two metrics is not

the sole criterion for determining groundwater protection. The presence of the chemical constituent available in mixed waste composition records is also considered as a reality check. Thus, there might be situations where an MCL is exceeded for groundwater even with treatment to UTS. However, that chemical constituent may either (1) not exist in the mixed waste universe, or (2) exist, but in low volumes. Neither of these two scenarios would represent a groundwater concern, even though a desktop comparison would indicate otherwise.

#### 4.1.1 Approach

Adjusted UTS values – referred to as Alternate Concentration Levels (ACLs) – were derived to reflect dilution and attenuation of constituents as they exit a landfill and are transported toward underlying groundwater. This derivation was achieved using either a Dilution Attenuation Factor (DAF) of 100 (if the constituent is a RCRA Toxicity Characteristic (TC) chemical) or the RCRA Hazardous Waste Identification Rule's 1995 (HWIR95) dilution attenuation factors (HWIR DAF) (US. EPA, 1999f). TC DAFs are normally 100 times Safe Drinking Water Standards. HWIR95 DAFs (see Table 4-1) were derived by groundwater modeling analyses for other hazardous waste constituents not listed under the Toxicity Characteristic rule. Thus, ACLs were computed as:

$$ACL = (UTS/DL)/DAF$$

where

DL = dilution correction factor of 20 for leaching test for organics; DL = 1 for metals.

#### 4.1.2 Results

Table 4-2 compiles MCL values, ACL values, and the ratio of ACL to MCL for constituents available. If the ratio for a chemical was found to be greater than 1.0, it was noted that this chemical's UTS may not provide a level of protection comparable to the MCL.

The following 18 of 66 chemicals had no listed UTS values:

alachlor	diquat
aldicarb	endothall
aldicarb sulfoxide	glyphosate
atrazine	methylene chloride
dalapon	picloram
1,1-dichloroethylene	nitrate (as nitrogen)
cis-1,2-dichloroethylene	nitrite (as nitrogen)
di (2-ethylhexyl) adipate	simazine
di (2-ethylhexyl) phthalate	styrene

**Table 4-1. HWIR95 Dilution Attenuation Factors**

Chemical	CAS No.	RCRA TC	HWIR95 DAF
D,2,4-	94-75-7	X	NAp
Alachlor	15972-60-8		NAv
Aldicarb	116-06-3		NAv
Aldicarb sulfoxide	1646-87-3		NAv
Aldicarb sulfone	1646-87-4		NAv
Atrazine	1912-24-9		NAv
Benzene	71-43-2	X	NAp
Benzo(a)pyrene	50-32-8		18
Carbofuran	1563-66-2		NAv
Carbon tetrachloride	56-23-5	X	NAp
Chlordane	57-74-9	X	NAp
Chlorobenzene	108-90-7	X	NAp
Cyanide	57-12-5		NAv
Dalapon	75-99-0		NAv
Dibromo-3-chloropropane, 1,2-	96-12-8		NAv
Dichlorobenzene, 1,2-	95-50-1		19
Dichlorobenzene, 1,4-	108-46-7	X	NAp
Dichloroethane, 1,2-	107-06-2	X	NAp
Dichloroethylene, 1,1-	75-35-4	X	NAp
Dichloroethylene, cis-1,2-	156-59-2		19
Dichloroethylene, trans-1,2-	156-60-5		19
Dichloropropane, 1,2-	78-87-5		33
Di (2-ethylhexyl) adipate	103-23-1		NAv
Di (2-ethylhexyl) phthalate	117-81-7		NAv
Dinoseb	88-85-7		NAv
Diquat	85-00-7		NAv
Endothall	145-73-3		NAv
Endrin	72-20-8	X	NAp
Ethylbenzene	100-41-4		19
Ethylene Dibromide	106-93-4		1500
Glyphosate	1071-53-6		NAv
Heptachlor	76-44-8	X	NAp
Heptachlor epoxide	1024-57-3	X	NAp
Hexachlorobenzene	118-74-1	X	NAp
Hexachlorocyclopentadiene	77-47-4		3.3E+06
Lindane	58-89-9	X	NAp
Methoxychlor	72-43-5	X	NAp
Methylene chloride	75-09-2		NAv

(continued)

**Table 4-1. (continued)**

Chemical	CAS No.	RCRA TC	HWIR95 DAF
Oxamyl (Vydate)	23135-22-0		NAv
Pentachlorophenol	87-86-5	X	NAP
Picloram	1918-02-1		NAv
Polychlorinated biphenyls	1336-36-3		NAv
Simazine	122-34-9		NAv
Styrene	100-42-5		19
TCDD, 2,3,7,8-	1746-01-6		18
Tetrachloroethylene	127-18-4	X	NAP
Toluene	108-88-3		19
Toxaphene	8001-35-2	X	NAP
Trichlorobenzene, 1,2,4-	120-82-1		19
Trichloroethane, 1,1,1-	71-55-6		19
Trichloroethane, 1,1,2-	79-00-5		19
Trichloroethylene	79-01-6	X	NAP
Trichlorophenoxypropionic acid, 2,4,5-	93-72-1	X	NAP
Vinyl chloride	75-01-4	X	NAP
Xylenes (total)	1330-20-7		19
Antimony	7440-36-0		34.3
Barium	744-39-3	X	NAP
Beryllium	7440-41-7		1.04E+02
Cadmium	7440-43-9	X	NAP
Chromium	18540-29-9	X	NAP
Fluoride	16984-48-8		NAv
Mercury	7439-97-6	X	NAP
Nitrate (as nitrogen)	NA		NAv
Nitrite (as nitrogen)	NA		NAv
Selenium	7782-49-2	X	NAP
Thallium (I)	7440-28-0		4.4E+01

CAS = Chemical Abstract Services Registry

TC = Toxicity Characteristic chemical (40 CFR 261.24)

DAF = Dilution Attenuation Factor

HWIR 95 = Hazardous Waste Information Rule; 1995 version

NAP = Not Applicable. Chemical is RCRA TC, thus assuming DAF = 100.

NAv is not available; no UTS or DAF.

UTS is as mg/kg except for metals where it is given as mg/l

Alternative Concentration Levels (ACL) = (UTS/DL)/DAF where

DL = dilution correction for leaching test is 20 (not applied to metals) and

DAF is 100 for TC constituents and HWIR95 DAF for landfills otherwise.

Source: U.S. EPA, 1999f.

**Table 4-2. Comparison of Maximum Contaminant Levels (MCL) to  
RCRA Universal Treatment Standards (UTS) for Land Disposal,  
Applying Dilution Attention Factors (DAF)**

Chemical	CAS No.	RCRA TC	MCL (Mg/l)	ACL (Mg/l)	ACL/MCL (Unitless)
D,2,4-	94-75-7	X	0.07	0.005	0.0714
Alachlor	15972-60-8		0.002	NA	NA
Aldicarb	116-06-3		0.003	NA	NA
Aldicarb sulfoxide	1646-87-3		0.004	NA	NA
Aldicarb sulfone	1646-87-4		0.002	NA	NA
Atrazine	1912-24-9		0.003	NA	NA
Benzene	71-43-2	X	0.005	0.005	1.0
Benzo(a)pyrene	50-32-8		0.0002	0.0094	47.0
Carbofuran	1563-66-2		0.04	NA	NA
Carbon tetrachloride	56-23-5	X	0.005	0.003	0.60
Chlordane	57-74-9	X	0.002	1.3E-04	0.065
Chlorobenzene	108-90-7	X	0.1	0.003	0.03
Cyanide	57-12-5		0.2	NA	NA
Dalapon	75-99-0		0.2	NA	NA
Dibromo-3-chloropropane, 1,2-	96-12-8		0.0002	0.0357	178.5
Dichlorobenzene, 1,2-	95-50-1		0.6	0.0158	0.0263
Dichlorobenzene, 1,4-	106-46-7	X	0.075	0.003	0.040
Dichloroethane, 1,2-	107-06-2	X	0.005	0.003	0.60
Dichloroethylene, 1,1-	75-35-4	X	0.007	NA	NA
Dichloroethylene, cis-1,2-	156-59-2		0.07	NA	NA
Dichloroethylene, trans-1,2-	156-60-5		0.1	0.079	0.790
Dichloropropane, 1,2-	78-87-5		0.005	0.0273	5.460
Di (2-ethylhexyl) adipate	103-23-1		0.4	NA	NA
Di (2-ethylhexyl) phthalate	117-81-7		0.006	NA	NA
Dinoseb	88-85-7		0.007	NA	NA
Diquat	85-00-7		0.02	NA	NA
Endothall	145-73-3		0.1	NA	NA
Endrin	72-20-8	X	0.002	6.5E-05	0.0325
Ethylbenzene	100-41-4		0.7	0.0263	0.0376
Ethylene dibromide	106-93-4		5.0E-05	0.0005	10
Glyphosate	1071-53-6		0.7	NA	NA
Heptachlor	76-44-8	X	0.0004	3.3E-05	0.0825
Heptachlor epoxide	1024-57-3	X	0.0002	3.3E-05	0.1650
Hexachlorobenzene	118-74-1	X	0.001	0.005	5.0
Hexachlorocyclopentadiene	77-47-4		0.05	3.636E-08	7.272E-07
Lindane	58-89-9	X	0.0002	3.3E-05	0.1650
Methoxychlor	72-43-5	X	0.04	9.0E-05	0.0023
(continued)					
Methylene chloride	75-09-2		0.005	NA	NA

**Table 4-2. (continued)**

Chemical	CAS No.	RCRA TC	MCL (Mg/l)	ACL (Mg/l)	ACL/MCL (Unitless)
Oxamyl (Vydate)	23135-22-0		0.2	NA	NA
Pentachlorophenol	87-86-5	X	0.001	0.0037	3.70
Picloram	1918-02-1		0.5	NA	NA
Polychlorinated biphenyls	1336-36-3		0.0005	NA	NA
Simazine	122-34-9		0.004	NA	NA
Styrene	100-42-5		0.1	NA	NA
TCDD, 2,3,7,8-	1746-01-6		3.0E-08	2.8E-06	93.33
Tetrachloroethylene	127-18-4	X	0.005	0.003	0.60
Toluene	108-88-3		1	0.0263	0.263
Toxaphene	8001-35-2	X	0.003	8E-07	0.0003
Trichlorobenzene, 1,2,4-	120-82-1		0.07	0.005	0.0714
Trichloroethane, 1,1,1-	71-55-6		0.2	0.0158	0.0790
Trichloroethane, 1,1,2-	79-00-5		0.005	0.0158	3.16
Trichloroethylene	79-01-6	X	0.005	0.003	0.60
Trichlorophenoxypropionic acid, 2,4,5-	93-72-1	X	0.05	0.004	0.080
Vinyl chloride	75-01-4	X	0.002	0.003	1.5
Xylenes (total)	1330-20-7		10	0.0789	0.0079
Antimony	7440-36-0		0.006	0.0335	5.583
Barium	744-39-3	X	2	0.21	0.105
Beryllium	7440-41-7		0.004	0.0117	2.92
Cadmium	7440-43-9	X	0.005	0.0011	0.22
Chromium	18540-29-9	X	0.1	0.006	0.06
Fluoride	16984-48-8		4.0	NA	NA
Mercury	7439-97-6	X	0.002	0.002	0.002
Nitrate (as nitrogen)	NA		10	NA	NA
Nitrite (as nitrogen)	NA		1	NA	NA
Selenium	7782-49-2	X	0.05	0.057	1.14
Thallium (I)	7440-28-0		0.002	0.0045	2.25

CAS No = Chemical Abstract Services Registry Number.

MCL = Safe Drinking Water Act Maximum Contaminant Level.

TC = Toxicity Characteristic chemical (40 CFR 261.24).

NA = Not available: either no UTS exists or no DAF exists.

Alternative Concentration Levels (ACL) = (UTS/DL)/DAF where

UTS = Universal Treatment Standard, which is expressed as mg/kg, except for metals, which is expressed as mg/L

DL = Dilution correction factor for leaching test (20 for organics; not applied to metals)

DAF = Dilution attenuation factor. DAF = 100 for TC chemicals. DAF = HWIR95 DAF for landfills for non-TC chemicals

HWIR95 = Hazardous Waste Identification Rule, 1995 versions (U.S. EPA, 1995f)

Of the 66 MCL contaminants, 25 had RCRA TC DAFs and 18 had HWIR95 DAFs available. Neither value was available for the following 23 constituents:

alachlor	endothall
aldicarb	glyphosate
aldicarb sulfoxide	methylene chloride
aldicarb sulfone	oxamyl (vydate)
atrazine	picloram
carbofuran	polychlorinated biphenyls
cyanide	simazine
dalapon	fluoride
di (2-ethylhexyl) adipate	nitrate (gas nitrogen)
di (2-ethylhexyl) phthalate	nitrite (as nitrogen)
dinoseb	
diquat	

The baseline list of constituents consisted of 66 MCL chemical contaminants. Of the 66 chemicals, ACL values were available for 41.

Results shown in Table 4-3 indicate that nine organic compounds and three metals exceeded the ratio of 1:

<b>Organics</b>	<b>Inorganics</b>
benzo(a)pyrene	antimony
1,2-dibromo-3-chloropropane	beryllium
ethylene dibromide	thallium
hexachlorobenzene	
pentachlorophenol	
2,3,7,8-TCDD	
1,1,2-trichloroethane	
vinyl chloride	
1,2-dichloropropane	

Next, these constituents were sought in an industry-provided database of utility nonwastewater hazardous wastes and associated waste quantities generated and stored. Table 4-3 contains these findings. To summarize, no volumes were reported for the five constituents whose ACL:MCL ratio was greater than 10: benzo(a)pyrene, 1,2-dibromo-3-chloropropane, dioxin, ethylene dibromide, and hexachlorobenzene. Seven constituents had ACL:MCL ratios less than 10 and greater than or equal to 1: 1,2-dichloropropane, pentachlorophenol, 1,1,2-trichloroethane, vinyl chloride, antimony, beryllium, and thallium. Of these, only one of the seven constituents was reported in the industry database with nonwastewater quantities: 1,1,2-trichloroethane, 5,452 kg.

**Table 4-3. Chemical Constituents Whose RCRA Universal Treatment Standards for Land Disposal Exceed Maximum Contaminant Levels**

Constituent	CAS No.	RCRA TC	ACL/MCL (unitless)	Utility database nonwastewater quantity generated and stored <sup>a</sup> (kg)
<b>Constituents with ACL/MCL ratios greater than or equal to 10</b>				
Benzo(a)pyrene	50-32-8		47	No volume report
Dibromo-3-chloropropane, 1,2-	96-12-8		179	No volume report
TCDD, 2,3,7,8- (dioxin)	1746-01-6		93	No volume report
Hexachlorobenzene	118-74-1	X	28	No volume report
Ethylene dibromide	106-93-4		10	No volume report
<b>Constituents with ACL/MCL ratios greater than 1</b>				
Dichloropropane, 1,2-	78-87-5		5	No volume report
Pentachlorophenol	87-86-5	X	4	No volume report
Trichloroethane, 1,1,2-	79-00-5		3	5,452
Vinyl chloride	75-01-4	X	2	No volume report
Antimony	7440-36-0		6	No volume report
Beryllium	7440-41-7		3	No volume report
Thallium	7440-28-0		2	No volume reported as thallium, thallium nitrate, or thallium carbonate

CAS No. = Chemical Abstract Services Registry Number.

MCL = Safe Drinking Water Act Maximum Contaminant Level.

TC = Toxicity Characteristic chemical (40 CFR 261.24).

UTS = Universal Treatment Standard, which is expressed as mg/kg except for metals which are given as mg/L.

ACL = Alternate Concentration Level.

ACL = (UTS/DL)/DAF where

DL = dilution correction for leaching test and is 20 (not applied for metals)

DAF = dilution attenuation factor. DAF = 100 for toxicity characteristic (TC) chemicals; DAF = HWIR95 DAF for landfills for non-TC chemicals

<sup>a</sup> Source: Roy F. Weston, et al., 1998.

### 4.1.3 Conclusions

This analysis shows a potentially limited number of hazardous waste constituents that may exceed their MCLs once leached from an NRC-regulated landfill where wastes are UTS compliant. However, it was reasonable to check the reality of the constituents lists by determining

- # If the wastes are being generated by the NRC-regulated utilities as nonwastewater wastes
- # If the generation rate is significant
- # If the wastes are likely to be land-disposed
- # If land-disposed, the mobility of the constituents based on their physical/chemical properties.

This screening analysis indicates that little potential exists for the contamination of groundwater for the chemical constituents where MCL and UTS values are available. In the situation where there is the potential for groundwater contamination, additional consideration of waste volume will eliminate all but 1,1,2-trichloroethane. Its volume is small (about 5,000 kg), especially when factored into total landfill capacity. In addition, trichloroethane is normally incinerated to achieve LDR standards.

## 4.2 Engineering Performance

### 4.2.1 A Predictive Comparison of Cover Design Performance at Selected NRC and EPA-Regulated Subtitle C Landfills

The purpose of this analysis is to compare the performance of landfill cover designs for hazardous waste and for LLRW. The comparison of cover designs is done for identified NRC cover designs from landfills in Utah, Washington, South Carolina, and California, and an assumed EPA design.

**4.2.1.1 Approach.** To compare the performance of different cover designs, an estimate of water that infiltrates through the covers for identical site conditions was used. Darcy's law was used to estimate the flow of water through the cover layers. Site-specific data were used where available and engineering judgment was used to assume reasonable values where data were unavailable. The intent of this analysis is to provide a quick analysis of the relative permeabilities of the cover designs being evaluated.

**4.2.1.2 EPA-Regulated Cover Design.** EPA issued regulations and guidance in July 1982 concerning closure and final cover for hazardous waste landfills (40 CFR 264.310(a)(5)). These regulations and the guidance appear to set minimum cover permeability requirements (i.e., the cover contains at least a 3-ft-thick,  $1 \times 10^{-7}$  cm/s permeability layer). RCRA cover regulations require that the final cover be no more permeable than the landfill's liner system.

Subtitle C landfills require a lower liner component with a 3-ft-thick (91 cm),  $1 \times 10^{-7}$  cm/sec permeability soil; a separate upper component (e.g., a geomembrane); and two leachate collection systems. In addition, the cover must be designed to function with minimum maintenance and to accommodate settlement and subsidence of the underlying waste. EPA recommends (U.S. EPA, 1989) that the final cover consist of, from bottom to top:

1. A low hydraulic conductivity soil layer. A 60-cm layer of compacted natural or amended soil with a hydraulic conductivity of  $1 \times 10^{-7}$  cm/s in intimate contact with a minimum 0.5-mm geomembrane liner with an assumed hydraulic conductivity of  $1 \times 10^{-9}$  cm/s.
2. A drainage layer. A minimum 30-cm soil liner with a minimum hydraulic conductivity of  $1 \times 10^{-2}$  cm/s, or a layer of geosynthetic material with the same properties.
3. A top, vegetative/soil layer. A top layer with vegetation and a minimum 60 cm of soil graded at a slope of 3 to 5 percent. A hydraulic conductivity of 42 cm/s is assumed for this layer.

**4.2.1.3 NRC-Regulated Cover Designs for Low-level Radioactive Wastes.** Unlike EPA, NRC land disposal regulations are performance-based rather than design specifications. Performance is based on a maximum human limit of radioactivity. However, LLRW landfill cover designs are generally comparable to EPA's multilayer design with some notable exceptions. One of the main differences in criteria is based on the fact that NRC designs have to last for thousands of years because of the long-lived radioactive waste they are covering (U.S. EPA, 1991). The long-term nature of their designs has minimized the use of geosynthetics, which are thought to have a finite service life.

In the absence of NRC regulatory design specifications for LLRW landfill covers, seven designs based on information from state authorities (who established site-specific design criteria) are used in this analysis. Six designs are for LLRW landfills; the seventh design is for an LLMW landfill. The seven designs evaluated in this analysis are listed below. The cover layers are listed from bottom-most to top-most layer.

**4.2.1.3.1 Design IA: Barnwell Site, SC (U.S. EPA 1999a).**

1. A low hydraulic conductivity clay layer: A 30.48-cm (12-in) layer of recompacted clay with an assumed hydraulic conductivity of  $1 \times 10^{-7}$  cm/s.
2. A 0.635-cm (0.25-in) bentonite mat with an assumed hydraulic conductivity of  $1 \times 10^{-7}$  cm/s.
3. A 0.152-cm (60-mil) thick high-density polyethylene (HDPE) geosynthetic liner with an assumed hydraulic conductivity of  $1 \times 10^{-7}$  cm/s.

4. A drainage layer: A 30.48-cm (12-in) sand drain layer for drainage with an assumed hydraulic conductivity of  $1 \times 10^{-2}$  cm/s.
5. A concrete vault: A 25.4-cm (10-inc) thick concrete vault with a hydraulic conductivity of  $1 \times 10^{-10}$  cm/s.
6. A top, vegetative/soil layer: A top layer with vegetation and a thickness of 152.4 cm (60 inches) with an assumed hydraulic conductivity of 42 cm/s.

**4.2.1.3.2 Design IB: Barnwell Site, SC, without concrete vault (U.S. EPA, 1999a).** Same cover layers as in Design IA, except that Layer 5, a concrete vault, is not present.

**4.2.1.3.3 Design II: Envirocare Site, UT (U.S. EPA, 1999b).**

1. A low hydraulic conductivity clay layer: A 182.88-cm (72-in) layer of compacted clay with a hydraulic conductivity of  $1 \times 10^{-6}$  cm/s.
2. A 30.48-cm (12-in) radon barrier layer with a hydraulic conductivity of  $5 \times 10^{-6}$  cm/s.
3. A filter zone 15.24 cm (6 inches) thick with a hydraulic conductivity of 3.5 cm/s.
4. A freeze/thaw layer 30.48 cm (12 inches) thick with a hydraulic conductivity of  $4 \times 10^{-3}$  cm/s.
5. A filter zone 15.24 cm (6 inches) thick with a hydraulic conductivity of 42 cm/s.
6. A top, rip rap layer 45.72 cm (18 inches) thick with a hydraulic conductivity of 42 cm/s.

**4.2.1.3.4 Design III: Enhanced Alternative A: Asphalt Infiltration Barrier, US Ecology, Richland, WA (U.S. EPA, 1999c).**

1. An interim cover of soil from site, 91.44 to 243.84 cm (36 to 96 inches) thick with an assumed hydraulic conductivity of  $1 \times 10^{-3}$  cm/s.
2. A grading fill of soil from site with compacted top surface, 0 to 152.4 cm (60 inches) thick with an assumed hydraulic conductivity of  $1 \times 10^{-4}$  cm/s.
3. A base course 30.48 cm (12 inches) thick of compacted gravel with an assumed hydraulic conductivity of  $1 \times 10^{-2}$  cm/s.
4. A barrier layer, 30.48 cm (12 inches) thick of asphalt with an assumed hydraulic conductivity of  $1 \times 10^{-8}$  cm/s.

5. A drainage layer of 30.48 cm (12 inches) thick topped by a geotextile filter layer with an assumed hydraulic conductivity of  $1 \times 10^{-2}$  cm/s.
6. Final cover of 15.24 cm (6 inches) of site soil with an assumed hydraulic conductivity of  $1 \times 10^{-4}$  cm/s.
7. A productivity layer of 100 percent silt loam soil 76.2 cm (30 inches) thick with an assumed hydraulic conductivity of  $1 \times 10^{-4}$  cm/s.
8. A gravel admix layer 76.2 cm (30 inches) thick of 15 percent pea gravel and 85 percent silt loam soil, topped by vegetation with an assumed hydraulic conductivity of  $1 \times 10^{-3}$  cm/s.

**4.2.1.3.5 Design IV: Enhanced Alternative B: Synthetic Infiltration Barrier, US Ecology, Richland, WA (U.S. EPA, 1999c).**

1. An interim cover of soil from site, 91.44 cm to 243.84 cm (36 to 96 inches) thick with an assumed hydraulic conductivity of  $1 \times 10^{-3}$  cm/s.
2. A grading fill of soil from site with compacted top surface, 60.96 to 213.36 cm (24 to 84 inches) thick with an assumed hydraulic conductivity of  $1 \times 10^{-4}$  cm/s.
3. A geosynthetic and geosynthetic clay liner barrier layer, 2 cm (<1 inch) thick with an assumed hydraulic conductivity of  $1 \times 10^{-9}$  cm/s.
4. A drainage layer of 30.48 cm (12 inches) thick of clean sand topped by a geotextile filter layer with an assumed hydraulic conductivity of  $1 \times 10^{-2}$  cm/s.
5. A site soil layer 15.24 cm (6 inches) thick with an assumed hydraulic conductivity of  $1 \times 10^{-4}$  cm/s.
6. Final cover/productivity layer 76.2 cm (30 inches) of 100 percent silt loam soil with an assumed hydraulic conductivity of  $1 \times 10^{-4}$  cm/s.
7. A gravel admix 76.2 cm (30 inches) thick of 15 percent pea gravel, 85 percent silt loam soil, topped by vegetation with an assumed hydraulic conductivity of  $1 \times 10^{-3}$  cm/s.

**4.2.1.3.6 Design V: Auger Hole Burial, Concrete and Soil Cover, US Ecology, Ward Valley, CA (U.S. EPA, 1999d).**

1. A 60.96-cm (24-in) thick cover of concrete with an assumed hydraulic conductivity of  $1 \times 10^{-7}$  cm/s.
2. A 441.96-cm (174-in) thick cover of soil from site with an assumed hydraulic conductivity of  $1 \times 10^{-4}$  cm/s.

3. A gravel cap 15.24 cm (6 inches) thick with an assumed hydraulic conductivity of  $1 \times 10^{-1}$  cm/s.

**4.2.1.3.7 Design VI: Envirocare Site Mixed Waste Landfill Cell, UT (U.S. EPA, 1999e).**

1. A low hydraulic conductivity clay layer: A 182.88-cm (72-in) layer of compacted clay with a hydraulic conductivity of  $1 \times 10^{-7}$  cm/s.
2. A 0.152-cm (60-mil) HDPE liner with an assumed hydraulic conductivity of  $1 \times 10^{-9}$  cm/s.
3. A drainage layer of 15.24 cm (6 inches) thick with an assumed hydraulic conductivity of  $1 \times 10^{-3}$  cm/s.
4. A 45.72-cm (18-in) thick Engineered Rock Armoring layer with an assumed hydraulic conductivity of  $1 \times 10^{-8}$  cm/s.

**4.2.1.4 Calculation of Flow Through Landfill Covers.**

**4.2.1.4.1 Formula Used for Estimation of Flow through Cover.** Flow rates through the liner are calculated using Darcy's law, which states:

$$Q = K I A \quad (4-1)$$

where

- $Q$  = flow rate,  $m^3/s$   
 $K$  = hydraulic conductivity of the soil, m/s  
 $I$  = dimensionless hydraulic gradient  
 $A$  = area over which the flow occurs,  $m^2$ .

If the soil is saturated and there is no soil suction, the hydraulic gradient  $I = (h + L) / L$  (Rumer and Ryan, 1995), where  $h$  is the depth of ponded water and  $L$  is the multilayered cover thickness.

**4.2.1.4.2 Depth of Ponded Water above Unit Cover Area ( $h$ ).** To use Equation 4-1 to calculate the flow through the cover, all the layers in the cover must be saturated. A thicker cover requires more water to reach saturation; thus, the volume of water to produce a 1-m depth of ponded water on a cover design varies by thickness of the cover. To make a fair comparison of the different covers, the water retained by layers in the cover design must be taken into account.

To compare the different cover designs, the depth of water added to all the cover designs is equal to the maximum value of the thicknesses of the covers being compared increased by 1 meter. This depth of water is then applied to all the cover designs to estimate the depth of water ponded above the cover. The thicker the cover, the lower the depth of ponded water above it for

the same quantity of water applied to it. The formula for calculating the water on each cover is expressed by Equation 4-2:

$$h = (d_{\max} + 1) - d \quad (4-2)$$

where

- h = depth of water above unit area of cover design being evaluated
- d<sub>max</sub> = maximum value of cover thickness of all the cover designs being evaluated
- d = total thickness of multilayered cover design being evaluated.

**4.2.1.4.3 Hydraulic Conductivity (K).** Where hydraulic conductivities of component layers in a cover design are available, Equation 4-3 was used to estimate the equivalent hydraulic conductivity (Rumer and Ryan, 1995).

$$k_{eq} = \frac{L_1 + L_2 + \dots + L_n}{\frac{L_1}{k_1} + \frac{L_2}{k_2} + \dots + \frac{L_n}{k_n}} \quad (4-3)$$

where

- k<sub>eq</sub> = equivalent hydraulic conductivity, cm/s
- L<sub>1</sub> = thickness of layer 1, cm
- L<sub>2</sub> = thickness of layer 2, cm
- k<sub>1</sub> = hydraulic conductivity of layer 1, cm/s
- k<sub>2</sub> = hydraulic conductivity of layer 2, cm/s.

**4.2.1.4.4 Time Period.** The flow of water through the cover designs is estimated for 1 year. The ranking of the cover designs would not change if we changed the time period for all the designs.

**4.2.1.4.5 Area over Which Flow Occurs (A).** The flow calculations are done for a 1-m<sup>2</sup> area of each cover design.

**4.2.1.4.6 Layer Thickness (L).** Liner thickness is equal to the total thickness of the cover designs being compared.

**4.2.1.5 Spreadsheet Modeling.** The methodology used in this analysis is presented in a Microsoft Excel<sup>TM</sup> spreadsheet model. The model was developed with the equations used in this analysis and can be used to enter different hydraulic conductivities and layer thicknesses to estimate flow through cover designs using Darcy's law and Equations 4-2 and 4-3. A screen-shot of the spreadsheet model is presented in Figure 4-1. The calculations for estimating the flow through the cover designs are presented in Table 4-4.

**4.2.1.6 Results of Analysis.** Table 4-5 indicates that the cover design's performance ranged from 0.001 m<sup>3</sup>/yr to 0.764 m<sup>3</sup>/yr, with the EPA cover design falling in the higher range at 0.367 m<sup>3</sup>/yr. In concluding this analysis, several simplifying assumptions were made:

1. Evapotranspiration effects for all the covers have been ignored. The analysis was done to compare the performance of a square foot of cover at the same site, and it is assumed that evapotranspiration effects are the same for all cover designs.
2. It was assumed that there is no drainage of water from the covers; i.e., water above the cover is ponded. The analysis does not account for the continuously decreasing head of water above the cover as water infiltrates through the cover.
3. It is assumed that water travels vertically through the layers and that water infiltration through punctures, cracks, or breaks in the liner systems are negligible. The analysis ignores the effects of intrusion by humans, animals, or plants; earthquakes; and erosion on water infiltration.
4. Where site-specific hydraulic conductivity data were not available, default values were assumed using engineering judgment and data from Freeze and Cherry (1979). Hydraulic conductivities for liner materials are an important parameter, and the results are highly dependent on data assumed.
5. This analysis is an easy-to-use screening level analysis of cover systems. Sophisticated computer models (e.g., UNSAT-H, HELP [U.S. EPA, 1994]) are available to more accurately predict the performance of landfill covers based on site-specific conditions.

## **4.2.2 Waste Containerization Technologies and Liner Systems**

This section addresses two engineering approaches to minimizing the release of hazardous constituents from landfills: waste containers and landfill liners. The waste containerization technology focuses on the performance of HICs – structures used at NRC-licensed landfills in which bulk waste or smaller containers are placed. Hazardous waste landfills are designed to detain leachate migration by installation of multiple layers of liners and leachate collection systems. These systems are normally comprised of a geomembrane liner, a leachate collection system, a compacted soil layer, and another leachate collection zone.

Cover Design Comparison Spreadsheet Model				
CALCULATIONS		Design I	Design II	Design III
Maximum Value of Cover Thickness + 1 (meters) =		7.5732	7.5732	7.5732
Depth of Pondered Water on Cover (meters) =		6.0727	1	2.3916
Area of Liner Used for Comparison (square meters) =		1	1	1
Time period over which Flow occurs (years) =		1	1	1
Quantity of Water through Cover for specified area, pondered depth, and time period (cubic meters) =		0.367	0.119	0.389

Design I RCRA design			
Layer Number	Layer Material	Hydraulic Conductivity (cm/sec)	Thickness of Layer (cm)
1	Low hydraulic conductivity soil layer	1.00E-07	60
2	Geomembrane layer	1.00E-09	0.05
3	Drainage layer	1.00E-02	30
4	Vegetative top layer	4.20E+01	60
5			
6			
7			
8			
9			
10			
Equivalent Hydraulic Conductivity (cm/sec) =		2.31E-07	
Total Thickness of Cover (cm) =			150.05

Design II Enhanced Alternative B: Synthetic Infiltration Barrier, Richland, WA			
Layer Number	Layer Material	Hydraulic Conductivity (cm/sec)	Thickness of Layer (cm)
1	Interim soil cover	1.00E-03	243.84
2	Grading fill of soil from site	1.00E-04	213.36
3	Geosynthetic and clay liner	1.00E-09	2
4	Drainage layer	1.00E-02	30.48
5	Site soil layer	1.00E-04	15.24
6	Final cover productivity layer	1.00E-04	76.2
7	Gravel admix	1.00E-03	76.2
8			
9			
10			
Equivalent Hydraulic Conductivity (cm/sec) =		3.28E-07	
Total Thickness of Cover (cm) =			657.32

Design III Deeper Depth Burial Trench, Ward Valley, CA			
Layer Number	Layer Material	Hydraulic Conductivity (cm/sec)	Thickness of Layer (cm)
1	Concrete cover	1.00E-07	60.96
2	Site soil cover	1.00E-04	441.96
3	Gravel cap	1.00E-01	15.24
4			
5			
6			
7			
8			
9			
10			
Equivalent Hydraulic Conductivity (cm/sec) =		8.44E-07	
Total Thickness of Cover (cm) =			518.16

Figure 4-1. Cover design comparison spreadsheet model.

**Table 4-4. Calculations for Estimation of Flow Through Cover**

Design Name	Hydraulic Conductivity and Thickness of Layers in Cover	Results of Calculations
<b>EPA design with clay infiltration barrier</b>	$k_1 = 1 \times 10^{-7}$ cm/s; $L_1 = 60$ cm $k_2 = 1 \times 10^{-9}$ cm/s; $L_2 = 0.05$ cm $k_3 = 1 \times 10^{-2}$ cm/s; $L_3 = 30$ cm $k_4 = 42$ cm/s; $L_4 = 60$ cm	<b>Area = 1 m<sup>2</sup> for all designs</b> <b>Time = 1 year for all designs</b> Equivalent hydraulic conductivity, $k_{eq} = 2.3 \times 10^{-7}$ cm/s Total cover thickness, $L = 1.50$ m Hydraulic head (h) = 6.072 m Flow through cover: <b><math>Q = K_{eq} \times A \times \text{Time} \times (h+L)/L</math></b> = 0.367 m <sup>3</sup>
<b>Design IA: Barnwell, SC Site design with recompacted clay, bentonite, HDPE liner, and concrete vault</b>	$k_1 = 1 \times 10^{-7}$ cm/s; $L_1 = 30.48$ cm $k_2 = 1 \times 10^{-7}$ cm/s; $L_2 = 0.635$ cm $k_3 = 1 \times 10^{-7}$ cm/s; $L_3 = 0.152$ cm $k_4 = 1 \times 10^{-3}$ cm/s; $L_4 = 30.48$ cm $k_5 = 1 \times 10^{-10}$ cm/s; $L_5 = 25.4$ cm $k_6 = 42$ cm/s; $L_6 = 152.4$ cm	Equivalent hydraulic conductivity, $k_{eq} = 9.41 \times 10^{-10}$ cm/s Total cover thickness, $L = 2.395$ m $h = 5.177$ m $Q = 0.001$ m <sup>3</sup>
<b>Design IB: Barnwell, SC, Site design with recompacted clay, bentonite, HDPE liner, without concrete vault</b>	$k_1 = 1 \times 10^{-7}$ cm/s; $L_1 = 30.48$ cm $k_2 = 1 \times 10^{-7}$ cm/s; $L_2 = 0.635$ cm $k_3 = 1 \times 10^{-7}$ cm/s; $L_3 = 0.152$ cm $k_4 = 1 \times 10^{-3}$ cm/s; $L_4 = 30.48$ cm $k_5 = 42$ cm/s; $L_5 = 152.4$ cm	Equivalent hydraulic conductivity, $k_{eq} = 6.84 \times 10^{-7}$ cm/s Total cover thickness, $L = 2.141$ m $h = 5.431$ m $Q = 0.764$ m <sup>3</sup>
<b>Design II: Envirocare, UT with clay barrier layers</b>	$k_1 = 1 \times 10^{-6}$ cm/s; $L_1 = 182.88$ cm $k_2 = 5 \times 10^{-6}$ cm/s; $L_2 = 30.48$ cm $k_3 = 3.5$ cm/s; $L_3 = 15.24$ cm $k_4 = 4 \times 10^{-3}$ cm/s; $L_4 = 30.48$ cm $k_5 = 42$ cm/s; $L_5 = 15.24$ cm $k_6 = 42$ cm/s; $L_6 = 45.72$ cm	Equivalent hydraulic conductivity, $k_{eq} = 4.03 \times 10^{-7}$ cm/s Total cover thickness, $L = 3.2$ m Head, $h = 4.372$ m Flow through cover, $Q = 0.301$ m <sup>3</sup>
<b>Design III: Richland, WA Enhanced alternative A: asphalt infiltration barrier</b>	$k_1 = 1 \times 10^{-3}$ cm/s; $L_1 = 243.84$ cm $k_2 = 1 \times 10^{-4}$ cm/s; $L_2 = 152.4$ cm $k_3 = 1 \times 10^{-2}$ cm/s; $L_3 = 30.48$ cm $k_4 = 1 \times 10^{-8}$ cm/s; $L_4 = 30.48$ cm $k_5 = 1 \times 10^{-2}$ cm/s; $L_5 = 30.48$ cm $k_6 = 1 \times 10^{-4}$ cm/s; $L_6 = 15.24$ cm $k_7 = 1 \times 10^{-4}$ cm/s; $L_7 = 76.2$ cm $k_8 = 1 \times 10^{-3}$ cm/s; $L_8 = 76.2$ cm	Equivalent hydraulic conductivity, $k_{eq} = 2.14 \times 10^{-7}$ cm/s Total cover thickness, $L = 6.553$ m Head, $h = 1.02$ m Flow through cover, $Q = 0.078$ m <sup>3</sup>

(continued)

**Table 4-4. (continued)**

Design Name	Hydraulic Conductivity and Thickness of Layers in Cover	Results of Calculations
<b>Design IV: Richland, WA Enhanced alternative B: synthetic infiltration barrier</b>	$k_1 = 1 \times 10^{-3} \text{ cm/s}$ ; $L_1 = 243.84 \text{ cm}$ $k_2 = 1 \times 10^{-4} \text{ cm/s}$ ; $L_2 = 213.36 \text{ cm}$ $k_3 = 1 \times 10^{-9} \text{ cm/s}$ ; $L_3 = 2 \text{ cm}$ $k_4 = 1 \times 10^{-2} \text{ cm/s}$ ; $L_4 = 30.48 \text{ cm}$ $k_5 = 1 \times 10^{-4} \text{ cm/s}$ ; $L_5 = 15.24 \text{ cm}$ $k_6 = 1 \times 10^{-4} \text{ cm/s}$ ; $L_6 = 76.2 \text{ cm}$ $k_7 = 1 \times 10^{-3} \text{ cm/s}$ ; $L_7 = 76.2 \text{ cm}$	Equivalent hydraulic conductivity, $k_{eq} = 3.28 \times 10^{-7} \text{ cm/s}$ Total cover thickness, $L = 6.573 \text{ m}$ Head, $h = 1 \text{ m}$ Flow through cover, $Q = 0.119 \text{ m}^3$
<b>Design V: Auger hole burial, concrete and soil cover, US Ecology, Ward Valley, CA</b>	$k_1 = 1 \times 10^{-7} \text{ cm/s}$ ; $L_1 = 60.96 \text{ cm}$ $k_2 = 1 \times 10^{-4} \text{ cm/s}$ ; $L_2 = 441.96 \text{ cm}$ $k_3 = 1 \times 10^{-1} \text{ cm/s}$ ; $L_3 = 15.24 \text{ cm}$	Equivalent hydraulic conductivity, $k_{eq} = 8.44 \times 10^{-7} \text{ cm/s}$ Total cover thickness, $L = 5.18 \text{ m}$ Head, $h = 2.391 \text{ m}$ Flow through cover, $Q = 0.389 \text{ m}^3$
<b>Design VI: Envirocare Mixed Waste Landfill, UT: Concrete, HDPE, and Clay liners</b>	$k_1 = 1 \times 10^{-8} \text{ cm/s}$ ; $L_1 = 45.72 \text{ cm}$ $k_2 = 1 \times 10^{-3} \text{ cm/s}$ ; $L_2 = 15.24 \text{ cm}$ $k_3 = 1 \times 10^{-9} \text{ cm/s}$ ; $L_3 = 0.1524 \text{ cm}$ $k_4 = 1 \times 10^{-7} \text{ cm/s}$ ; $L_4 = 182.88 \text{ cm}$	Equivalent hydraulic conductivity, $k_{eq} = 3.72 \times 10^{-8} \text{ cm/s}$ Total cover thickness, $L = 2.43 \text{ m}$ Head, $h = 5.133 \text{ m}$ Flow through cover, $Q = 0.036 \text{ m}^3$

**Table 4-5. Results of Comparison of Cover Designs**

Rank	Design Name	Design Information
1	Design IA: Barnwell, SC Site design with recompacted clay, bentonite, and HDPE liners, and concrete vault	$k_{eq} = 9.41 \times 10^{-10}$ cm/s $L = 2.395$ m $Q = 0.001$ m <sup>3</sup>
2	Design VI: Envirocare Mixed Waste Landfill, UT, Design with concrete, HDPE, and clay barrier layers	$k_{eq} = 3.72 \times 10^{-8}$ cm/s $L = 2.43$ m $Q = 0.036$ m <sup>3</sup>
3	Design III: Enhanced Alternative A: Asphalt Infiltration Barrier, US Ecology, Richland, WA	$k_{eq} = 2.14 \times 10^{-7}$ cm/s $L = 6.553$ m $Q = 0.078$ m <sup>3</sup>
4	Design IV: Enhanced Alternative B: Synthetic Infiltration Barrier, US Ecology, Richland, WA	$k_{eq} = 3.28 \times 10^{-7}$ cm/s $L = 6.573$ m $Q = 0.119$ m <sup>3</sup>
5	Design II: Envirocare, UT, Design with clay barrier layers	$k_{eq} = 4.03 \times 10^{-7}$ cm/s $L = 3.2$ m $Q = 0.301$ m <sup>3</sup>
6	EPA Design with clay infiltration barrier	$k_{eq} = 2.3 \times 10^{-7}$ cm/s $L = 1.50$ m $Q = 0.367$ m <sup>3</sup>
7	Design V: Auger Hole Burial, Concrete and Soil Cover, US Ecology, Ward Valley, CA	$k_{eq} = 8.44 \times 10^{-7}$ cm/s $L = 5.18$ m $Q = 0.389$ m <sup>3</sup>
8	Design IB: Barnwell, SC; Site design with recompacted clay, bentonite, and HDPE liners, without concrete vault	$k_{eq} = 6.84 \times 10^{-7}$ cm/s $L = 2.141$ m $Q = 0.764$ m <sup>3</sup>

Rank 1 is the best performing cover and Rank 8 is the least effective cover in preventing water infiltration.

The previous section on covers demonstrates the performance suitability of the EPA and NRC-regulated designs. In addition, EPA also relies on an extensive liner/leachate collection system to control leachate production from bulk waste disposal. On the other hand, NRC's philosophy is to have containerization as another engineering structure to (1) support covers and (2) protect intruders, as well as (3) create a barrier to liquid/waste interaction. The NRC philosophy is to minimize liquid/waste contact and subsequent residence time. This is attributed to the radionuclide decay attributes of the waste and minimization of leachate concentration due to the development of equilibrium concentrations. While EPA-regulated RCRA landfills will develop minimal freeboard on top of the bottom liner, the leachate collection system will remove the leachate for subsequent treatment.

#### **4.2.2.1 Waste Containerization Technologies**

**4.2.2.1.1 Approach.** This investigation was conducted through the review of

- # Online (Internet) documents pertaining to: (1) low-level radioactive and mixed-waste disposal and container use at commercial and government facilities, (2) waste stabilization technologies and performance, and (3) material corrosion
- # Performance assessment reports for NRC-regulated facilities
- # Pertinent EPA and NRC regulations
- # Available vendor information.

Little information was found that directly compares the performance of containers typically used by EPA disposal facilities to those used by NRC-regulated facilities. Therefore, the approach selected for this investigation was to compare the absolute protection of HICs described in the NRC's *Technical Position on Waste Form (Revision 1)* (U.S. NRC, 1991) to a typical EPA container (carbon steel) and its expected performance. Additionally, the HIC performance criteria were compared at two NRC-regulated disposal facilities located in diverse climates.

**4.2.2.1.2 High-integrity Containers.** An HIC is defined as a container commonly designed to meet the structural stability requirements defined in 10 CFR 61.56 and to meet Department of Transportation (DOT) requirements for a Type A package. The composition of an HIC may vary, but shall not be composed of fiberboard or cardboard (10 CFR 61.56(a)(1)). Examples include stainless steel or carbon steel boxes or drums, reinforced concrete, polymeric materials, and composites. A summarization of requirements for HICs as designated in the NRC *Technical Position on Waste Form* is provided below (U.S. NRC, 1991):

- # Maintain free liquids less than 1 percent of waste volume
- # Design for 300 years of structural integrity
- # Consider corrosive and chemical effects of wastes and disposal environment
- # Provide sufficient mechanical strength to withstand loads equivalent to proposed burial; also transportation, loading, and disposal site operations, and creep (polymeric materials)
- # Consider thermal loads from processing, transportation, and burial
- # Consider radiation stability of container and effects of radiation degradation and ultraviolet radiation (polymeric materials)
- # Consider biodegradation properties of container and wastes

- # Avoid collection and retention of water on top surfaces
- # Maintain positive seal for lifetime of container.

U.S. NRC (1991) suggests that prototype testing be performed on the HIC and that the HIC should be designed, fabricated, and used in accordance with a quality control (QC) program.

**4.2.2.1.3 Comparison of NRC-Regulated HICs to EPA-Regulated Containers.** This section compares the performance of containers in two scenarios:

- # Baseline container: carbon steel drum used by both EPA and NRC-regulated facilities.
- # NRC-regulated HICs that meet NRC design guidelines.

**Scenario 1: Baseline Carbon Steel Containers.** According to 40 CFR 264.171 and 264.172 of EPA regulations, containers used to store hazardous waste must be in good condition and the container and/or liner must be compatible with the wastes to be stored within them. There are a variety of container types with varying capacities that can be used to store hazardous waste, including:

- # Carbon steel, stainless steel, galvanized, and aluminum drums (lined and unlined, open-top and bung-type opening)
- # Polyethylene carboys and drums
- # Fiber drums (dry waste only)
- # Glass jars and bottles
- # Fabric, paper, and plastic bags
- # Corrugated boxes.

A 55-gallon carbon steel drum was selected as being the most common type of container used for a wide variety of hazardous wastes. Therefore, the expected performance of a 55-gallon drum was compared as a baseline to HICs specified by the NRC.

Because EPA-regulated land disposal facilities are designed and permitted to maintain their structural (and protective) integrity through 30 years of postclosure care, it is presumed that containers used in EPA facilities maintain their structural integrity for a minimum of 30 years. However, the integrity of a carbon steel drum will depend on: (1) the disposal environment (i.e., drums disposed of in an arid environment will likely outperform drums disposed of in a humid environment), and (2) drum coatings/liners and waste compatibility with materials of drum construction. Other than damage inflicted during transport or handling, the most significant

threat to the integrity of a steel drum is corrosion; although the use of drum liners/overpacks will reduce the occurrence of drum corrosion.

Testing conducted by Lawrence Livermore National Laboratory (LLNL, 1998) on the corrosion of a variety of steel alloys, including carbon steel, indicated that corrosion rates vary extensively and are sensitive to subtleties of environment, stresses, and metallurgical processing. The LLNL testing was performed to evaluate carbon-steel outer layers to be used for HICs, and several conditions were simulated including high temperatures, varying water/vapor contact, and varying ionic concentrations in the contact water. The LLNL document reported that several years are required to arrive at a steady-state corrosion rate; however, average general corrosion rates for carbon steel (Type A516) varied from 6 to 76  $\mu\text{m}/\text{yr}$ . Assuming a drum has a wall thickness of 1 mm, the inferred period of performance for the drum would be on the order of 13 to 166 years. No additional sources of carbon-steel degradation were investigated for this assignment.

**Scenario 2: NRC-regulated HICs.** For this assignment, LLW disposal techniques were compared for two NRC-licensed facilities, the Chem Nuclear Systems, Inc. (CNSI) site in Barnwell, SC, and the Envirocare disposal facility in Clive, UT.

**Barnwell Site.** Information on the containerization and disposal of LLRW at the Barnwell Site was obtained from a South Carolina Department of Health and Environmental Control (SC DHEC) technical evaluation (U.S. EPA, 1999a). South Carolina Radioactive Material License No. 097 issued to CNSI has a condition that stipulates that all classes of waste must be disposed of in concrete vaults. SC DHEC's Technical Evaluation Report determined whether the vault will meet the state regulatory requirements. Sections of the U.S. NRC *Technical Position on Waste Form* (U.S. NRC, 1991) concerning structural stability in a shallow land disposal environment was used as guidance in the evaluation.

The primary functions of the concrete vault are to provide a structure that will completely support all loads imposed by the burial environment, thereby reducing subsidence in the trench caps and providing additional containment for the wastes. Minimizing subsidences is necessary to ensure that the multi-layer trench cap will perform as designed. The concrete vault will also serve as an intruder barrier and reduce the amount of water infiltration into the waste.

To evaluate the vault, CNSI submitted responses to questions concerning the new technology as well as specific vault details, including the structural analysis ST-168 "Application for Concrete Vault for Waste Disposal, Barnwell Waste Management Facility." All six sides of the vault are 8 inches thick.

On September 21, 1995, CNSI requested the approval of the cylindrical concrete vaults for use in Class A waste trenches. The cylindrical vault was previously approved by SC DHEC for use in the disposal of Class B and C waste. The cylindrical vault has been in use at the Barnwell site since 1989.

The overall dimensions of the rectangular concrete vault are 11 feet long, 9 feet wide, and 10 feet, 8 inches high. The lid of the vault is separate and adds an additional 8 inches to the vault height. All six sides of the vault are 8 inches thick.

The concrete vaults are constructed of portland cement concrete with a minimum compressive strength of 5,000 psi and reinforced with conventional #4 and 5 steel reinforcing bars. The concrete mix design incorporates pozzolans, a low water-to-binder ratio, non-reactive aggregates, and water-reducing admixtures.

Lowering the permeability of the concrete used to construct the concrete vaults is extremely important to insure the durability and longevity of the structure. The mixture also employs the use of pozzolanic material as additives to fill voids normally left in solidified concrete.

The durability of the concrete structure is based on designing the vault shell for the thickness necessary to provide the mechanical strength due to overburden, resist applied loads due to site operations and maintain structural integrity for minimum 300-year life.

The concrete vault was designed in accordance with the NRC "Revised Staff Technical Position on Waste Form," (SP-91-13) and the "DHEC Guide for High Integrity Container Topical Report Topical Applications." The guidance provided by the two documents were originally developed for the review of high integrity container topical report applications, however, the stability requirements found in the documents were applied to the concrete vault.

Various properties of soils can potentially affect the life of the concrete vault. Three notable components of concrete degradation include decalcification, sulfate attack, and chloride attack. Given Barnwell's soil conditions, only degradation of concrete structures due to chlorides must be addressed. Chlorides typically act to corrode reinforcing steel in structures. Generally, the concentration of water soluble chlorides in backfill at the Barnwell disposal site is less than 5.2 ppm.

The concrete vault must display sufficient mechanical strength to withstand horizontal and vertical loads to a depth of 40 feet. This is based on a trench depth of 25 feet and a mounded cover with a total thickness of 15 feet.

Pursuant to CNSI's request to use the rectangular concrete vault for disposal of Class A LLRW, approval was granted by SC DHEC. Analysis of the vaults has shown a sufficient factor of safety for the container's mechanical strength in shallow land disposal. It should be noted that the concrete erosion rate presented for a concrete vault at the nearby Savannah River Site (SRS) is 0.1 m per 1,000 years. For the purposes of the modeling of any releases from that facility, the vault roof was predicted to remain intact (crack-free) for 1,400 years. An SRS radiological performance assessment indicated that the roof would not collapse for 3,100 years (Martin Marietta, 1994).

**Envirocare Disposal Facility.** The Envirocare facility in Clive, UT, is the only commercial facility in the country licensed to receive mixed waste. Envirocare uses a

polyethylene macroencapsulation process for containerization/disposal of mixed waste. The process uses a plastics extruder to melt, convey, and pump molten polyethylene into a waste container in which the waste materials have been suspended or supported (Brookhaven National Laboratories, 1998). Studies indicate that macroencapsulation is a more durable waste stabilization/containment technology with a compressive strength greater than cement-based stabilization technologies (Steele and Mayberry, 1994). Testing of the durability properties of the polyethylene jacket, such as compressive strength, resistance to saturated conditions, thermal cycling, microbial degradation, ionizing radiation, and leaching (Kalb et al., 1993), found this stabilization method to be very durable. A comparison of waste-form performance that included testing of portland cement, sulfur polymer cement, phosphatic ceramic, and polyethylene micro- and macroencapsulation concluded that there were no practical limitations of polyethylene macroencapsulated waste (based on leaching, compressive strength, waste loading, and resistance to biodegradation and irradiation) (Ramsey, 1993). A high-density polyethylene (HDPE) overpack was granted a 300-year life rating by SC DHEC (Ramsey, 1993).

**4.2.2.2 Liner Systems.** Disposal of uncontainerized hazardous waste in a properly lined RCRA Subtitle C landfill arguably provides for sufficiently protective containment when compared to NRC HICs. This is because Subtitle C landfills require two bottom liners, i.e., an upper synthetic liner, a 3-ft (91-cm) thick lower soil liner with a permeability of at least  $1 \times 10^{-7}$  cm/sec, and two leachate collection systems (40 CFR 264.301). This RCRA design not only provides dual barriers to leachate migration but also provides two opportunities to detect and collect leachate that may penetrate either liner.

Although liners comply with a 30-year postclosure care requirement in RCRA, the geomembranes used in landfills have been estimated to last approximately 70 to 1,000 years when properly installed, according to research findings of the Geosynthetic Institute at Drexel University (Kroener, 1999). Studies have found HDPE (the synthetic material from which geomembranes are produced) to carry the following lifetime estimates:

1.	Antioxidant Depletion	= 50 to 150 years
2.	Induction Time	= 20 to 30 years
3.	Half-life Estimate	
	# Gas pipe application	= 200 years
	# Cable shielding app.	= 750 years
TOTAL (estimate)		= 270 to 1,000 years

The Institute researchers found that upon depletion of antioxidant resins (50 to 150 year), an induction period of 20 to 30 years occurs before actual degradation of the synthetic material begins. Upon degradation, industry research has shown the life of the material ranges from 200 to 750 years (based on a 1983 gas pipe degradation study by the Gas Research Institute and a 1987 cable shielding study by Underwriters Laboratory, respectively [Kroener, 1999]).

Table 4-6 summarizes the performance information presented above on HICs and RCRA liner research.

**Table 4-6. Performance Information on Traditional Containers,<sup>a</sup> High-Integrity Containers, and RCRA Liner Systems**

Scenario	Design Life (years)	Predicted Actual Life (years)	Maximum Life (years)
<b>Baseline</b> - carbon steel drum	30 (EPA-required postclosure care period)	13-166 (potential corrosion rate of carbon steel)	> 13-166 (assuming steel is coated/lined)
<b>Concrete vault</b>	300 (NRC <i>Technical Position</i> specifications)	1,400 (estimated time that vaults are to remain intact - SRS) <sup>b</sup>	1,400-3,100 (assumed collapse of vault roof - SRS) <sup>b</sup>
<b>Polyethylene macroencapsulation</b>	300 (NRC <i>Technical Position</i> specifications)	300 (testing for SC Dept. Of Health)	>300 years (in an arid, NRC-regulated facility)
<b>RCRA liner systems</b>	30-year (EPA-required postclosure care period)	70-180 (Kroener, 1999)	270-1,000 (Kroener, 1999)

<sup>a</sup> EPA regulations do not require disposal of hazardous waste in containers so long as it is not a liquid waste.

<sup>b</sup> Although the Savannah River Site is not an NRC-licensed facility, its studies provide valuable performance analyses of the concrete vault technology.

## 5.0 Operating History and Groundwater Monitoring of NRC-Regulated Facilities

The protection of groundwater is the major issue associated with the disposal of waste in land-based disposal facilities. This issue is highlighted for the disposal of mixed waste at LLRW disposal facilities because of the difference in liner requirements between the NRC and EPA regulatory programs. Previous discussion in this document has presented the benefits of waste treatment and containerization. This section describes the layout of groundwater monitoring wells and the operating performance histories at three commercial radioactive waste disposal facilities. The information presented is the collection of communications with state radioactive waste and hazardous waste agency staff and EPA regional staff.

The lack of explicit NRC liner requirements at licensed radioactive waste disposal facilities does raise concern about the potential migration of hazardous constituents into the environment. It should be noted that, although no liner requirement exists in 10 CFR Part 61, the Envirocare of Utah LLW cell (built after the promulgation of NRC's LLWDF regulations in 1982) does have a subwaste layer of compacted clay with a permeability of  $10^{-6}$  cm/s. The current monitoring program at these LLRW facilities is for radioactive constituents as specified in the NRC license. From this information one cannot make absolute statements concerning the migration of hazardous constituents out of the unit because of physical and chemical behavior variations among the hazardous constituents and between these constituents and the radioactive constituents. One can, however, address the groundwater monitoring well layout at the facilities with regard to what is used for hazardous constituent monitoring. The 40 CFR Part 264.95 regulation on groundwater monitoring well locations specifically states locating wells at "the point of compliance .... at the hydraulically downgradient limit of the waste management unit," but the regulation does not state the number of wells to install. Only in 40 CFR Part 265.91 are the location and number of wells identified. Additional wells may be located according to 40 CFR Part 264.97. Similar flexibility is seen in NRC's 10 CFR Part 61.53. In addition, the historical groundwater monitoring performance for radioactive constituents could be used in evaluating the historical performance of the disposal unit and the need for additional monitoring wells.

### 5.1 Groundwater Monitoring Wells

The placement of groundwater monitoring wells at LLRW disposal facilities is variable and reflects the site-specific, subsurface attributes of the site. The three facilities that were investigated – CNSI (Barnwell, SC), Envirocare of UT (CLive, UT), US Ecology (Richland, WA) – had monitoring systems that were identified to meet the NRC requirements for early detection and mitigation within the buffer zone.

The US Ecology facility has seven groundwater monitoring wells located from approximately 40 feet from a disposal cell boundary to offsite. In addition to the groundwater monitoring wells, there are three vadose zone monitoring wells located from the cell to the property boundary.

The Envirocare facility's Section 32 holds the 11e(2) low-level radioactive waste and mixed waste cells and has 43 groundwater monitoring wells. Fourteen wells encircle the LLRW cell. The wells range from approximately 50 to 200 feet from the unit boundary, with the buffer zone set at 300 feet and the property line outside of the buffer zone.

The CNSI facility has approximately 200 groundwater monitoring wells, in part because of its location in the humid southeastern United States. These wells are sampled quarterly and yearly. The groundwater monitoring wells are located from just off the disposal cell boundary to approximately 2,400 feet downgradient.

## **5.2 Operating Performance History**

The groundwater monitoring histories of all three facilities are available for more than 10 years and, in some cases, more than 20 years. All three facilities have groundwater monitoring programs, while US Ecology also has vadose zone monitoring. The groundwater monitoring programs range from quarterly to yearly sampling for radioactive constituents specified in the facilities' licenses.

The Envirocare facility has not detected groundwater contamination for radioactive constituents attributed to the unit. Based on the compliance history of the facility, Envirocare has been approved to accept CERCLA offsite wastes. If problems had existed at the facility for groundwater contamination and compliance history, the facility would not be able to accept these wastes.

The US Ecology facility has not detected groundwater contamination from radioactive constituents at the time of the facility's report. The groundwater aquifer is approximately 285 feet below the disposal trenches. The Washington Department of Health has reported seeing elevated levels of tritium in groundwater that the Department believes is encroaching from the DoE Hanford operations. However, there has been detection of radioactive constituents in the vadose zone, but below regulatory levels. A comprehensive subsurface investigation for the US Ecology site has been completed, and the data are currently being processed but will not be available until the fall of 1999. This work will be followed to further refine EPA's analysis and position on disposal site protectiveness. The facility is also approved to accept CERCLA offsite wastes based on its compliance status and history.

The CNSI facility reported that there was no groundwater contamination from the disposal units constructed after the NRC's promulgation of 10 CFR Part 61. However, tritium releases to groundwater were detected at concentrations below regulatory levels from disposal units constructed and operated before 10 CFR 61 regulations were adopted. The State of South Carolina and CNSI have decided not to accept CERCLA offsite waste, so the status of the facility concerning groundwater compliance is not known.

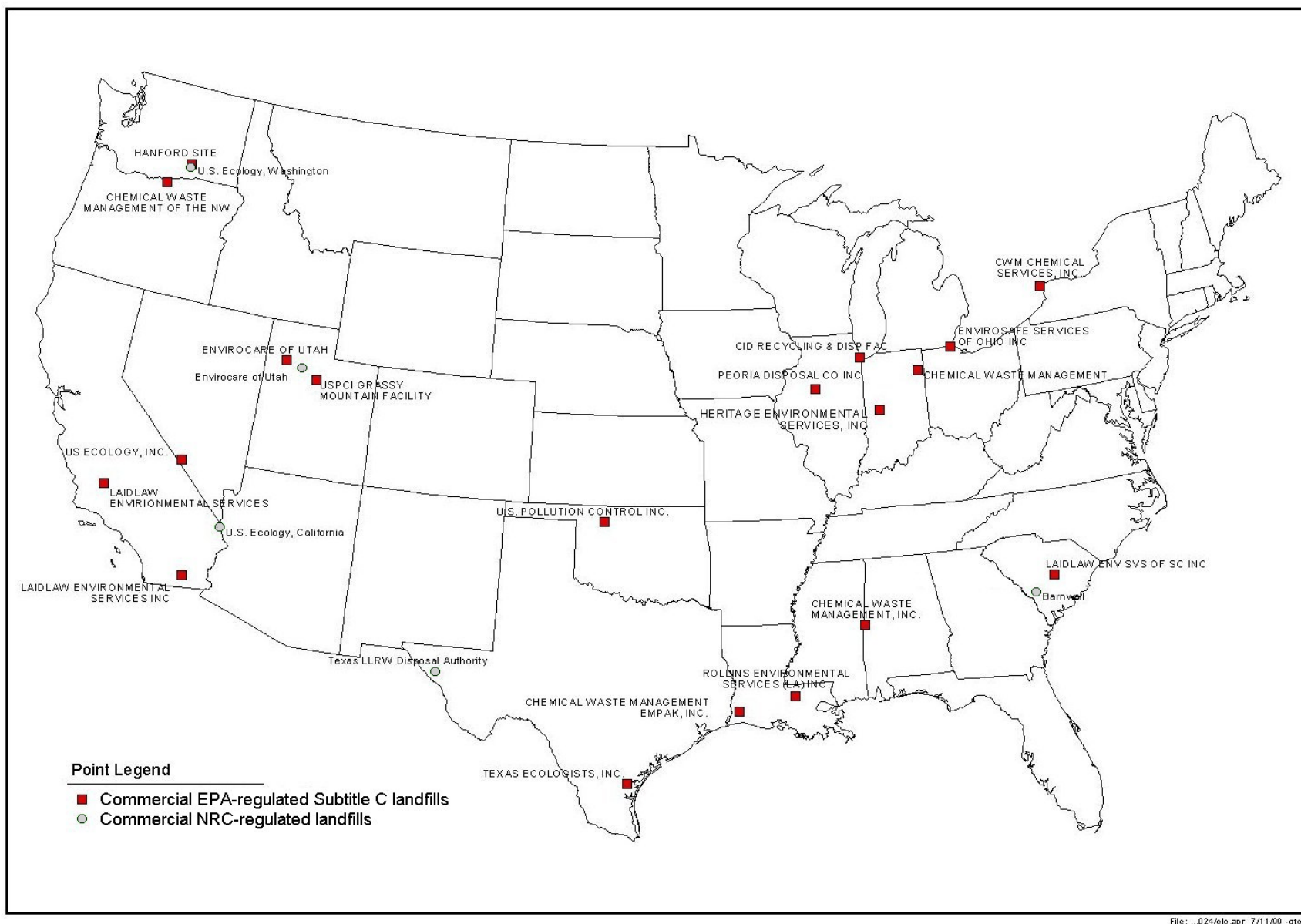
## **6.0 Comparison of Commercial NRC-Regulated Landfills to Commercial EPA-Regulated RCRA Subtitle C Landfills: Hydrogeologic and Other Physical Characteristics**

The current EPA paradigm for hazardous waste disposal is treatment to LDRs followed by disposal in a RCRA Subtitle C disposal unit (landfill). To support the analysis of protection achieved from mixed waste disposal NRC-licensed LLRW landfills, a comparison of hydrogeologic and other physical characteristics was conducted for commercial EPA-regulated RCRA Subtitle C landfills versus commercial NRC-regulated landfills.

### **6.1 Approach**

As part of this overall comparison, receptor distance was examined along with climatic, soil, hydrogeologic, and unit characteristics that can impact health risks through the groundwater pathway for the different types of units regulated by EPA and NRC Agreement States. Figure 6-1 maps the NRC and EPA-regulated Subtitle C landfills considered in this analysis. Table 6-1 provides the name, address, location, and EPA Facility ID for each site. The 19 Subtitle C sites were selected by EPA as active, commercial landfills from a preliminary list developed from the Resource Conservation and Recovery Information System (RCRIS) and Biennial Reporting System (BRS) databases. Facility locations were obtained from EPA's Envirofacts system and other sources noted in Table 6-1.

The general approach was to obtain information from the best available source. Site-specific documentation was used wherever possible. Where site-specific data were not available, national data sources and semiautomated data collection methods were used to obtain information. More detailed information is provided below by data element.



**Figure 6-1. Geographic distribution of commercial EPA-regulated Subtitle C landfills and commercial NRC-regulated landfills.**

**Table 6-1. NRC- and EPA-Regulated Subtitle C Commercial Landfills**

<b>Site Abbreviation</b>	<b>Site Name</b>	<b>Location</b>
<b><i>Commercial NRC-regulated Landfills</i></b>		
BW	Barnwell	Near Barnwell, SC 33.241 lat., -81.365 long. (city centroid <sup>a</sup> )
EU	Envirocare of Utah (LLRW)	Tooele County, UT 40.544 lat., -112.378 long. (Envirofacts; zip code centroid)
TLLRW	Texas LLRW Disposal Authority	S. Hudspeth Co., TX 31.129 lat., -105.254 long. (Envirofacts, PCS)
USE CA	U.S. Ecology, CA	N. Ward Valley, Mojave Des., CA 34.842 lat., -114.593 long. (map location; USE, 1990)
USE WA	U. S. Ecology, WA	Near Richland, WA 46.294 lat., -119.291 long. (city centroid <sup>a</sup> )
<b><i>Commercial EPA-regulated Subtitle C Landfills</i></b>		
CID	CID Recycling and Disposal Facility EPAID ILD010284284	Calumet City, IL 41.665 lat., -87.561667 long. (Envirofacts, unknown)
CWM Emelle	Chemical Waste Management, Inc. EPAID ALD000622464	Emmelle, AL 32.795833 lat., -88.309444 long. (Envirofacts, AIRS)
CWM Fort Wayne	Chemical Waste Management, Inc. EPAID IND078911146	Fort Wayne, IN 41.047222 lat., -85.062778 long. (Envirofacts, unknown)
CWM Model City	CWM Chemical Services, Inc. EPAID NYD049836679	Model City, NY 43.215556 lat., -79.052778 long. (Envirofacts, interpolation- map)
CWM NW	Chemical Waste Management of the NW EPAID ORD089452353	Arlington, OR 45.610719 lat., -120.204042 long. (Envirofacts, zip code centroid)
CWM Sulphur	Chemical Waste Management, Inc. EPAID LAD000777201	Sulphur, LA 30.119827 lat., -93.403732 long. (Envirofacts, interpolation- map)
Envirocare	Envirocare of Utah EPAID UTD982598898	Clive, UT 40.683 lat., -113.108 long. (Envirofacts, interpolation- map)
Envirosafe	Envirosafe Services of Ohio, Inc. EPAID OHD045243706	Oregon, OH 41.66743 lat., -83.468362 long. (Envirofacts, address matching- house number)
Hanford	Hanford Site EPAID WA7890008967	Richland, WA 46.3835 lat., -119.282333 long. (Envirofacts, GPS- unspecified)

(continued)

**Table 6-1. (continued)**

Site Abbreviation	Site Name	Location
<i>Commercial EPA-regulated Subtitle C Landfills (continued)</i>		
Heritage	Heritage Environmental Services, Inc. EPAID IND980503890	Roachdale, IN 39.844833 lat., -86.924111 long. (Envirofacts, RCRIS)
LES Buttonwillow	Laidlaw Environmental Services, Inc. EPAID CAD980675276	Buttonwillow, CA 35.4 lat., -119.61111 long. (Envirofacts, RCRIS)
LES Pinewood	Laidlaw Environmental Services of SC, Inc. EPAID SCD070375985	Pinewood, SC 33.688333 lat., -80.527778 long. (Envirofacts, RCRIS)
LES Westmorland	Laidlaw Environmental Services, Inc. EPAID CAD000633164	Westmorland, CA 33.028398 lat., -115.692606 long. (Envirofacts, address matching-digitized)
Peoria	Peoria Disposal Co. EPAID ILD000805812	Peoria, IL 40.721667 lat., -89.66 long. (Envirofacts, unknown)
Rollins	Rollins Environmental Services, (LA) Inc. EPAID LAD010395127	Baton Rouge, LA 30.567778 lat., -91.215556 long. (Envirofacts, interpolation- map)
Texas Eco	Texas Ecologists, Inc. EPAID TXD069452340	Robstown, TX 27.729053 lat., -97.658318 long. (Envirofacts, interpolation- map)
USEco Beatty (This is not the radioactive waste disposal site)	US Ecology, Inc. EPAID NVT330010000	Beatty, NV 36.769167 lat., -116.689722 long. (Envirofacts, RCRIS)
USPCI OK	US Pollution Control, Inc. EPAID OKD065438376	Waynoka, OK 36.4375 lat., -98.805 long. (Envirofacts, interpolation- map)
USPCI UT	USPCI Grassy Mountain Facility EPAID UTD991301748	Knolls, UT 40.208 lat., -111.68 long. (Envirofacts, interpolation- map)

<sup>a</sup> Approximate latitude/longitude from city centroid; unable to determine specific locations. Use for nationwide map only.

AIRS = Aerometric Information Retrieval System

PCS = Permit Compliance System

GPS = Global Positioning System

RCRIS = Resource Conservation and Recovery Information System

## 6.2 Summary and Conclusions

Several general conclusions are apparent with regard to the physical and hydrogeologic comparability of the commercial hazardous waste landfills and LLRW disposal facilities:

- # The eight western EPA-regulated landfills are very similar to the NRC-regulated sites, with some EPA-regulated sites being co-located with NRC-regulated landfills. The generally isolated locations of these landfills results in long receptor well distances (actual or hypothetical).
- # Many of the western EPA-regulated and NRC-regulated disposal facilities are in arid climates which generally have deep water tables (thick unsaturated zones) and low recharge and infiltration rates. Although the eastern sites generally experience higher precipitation than the western sites, recharge and infiltration rates at these sites tend to be limited by low-permeability soils.
- # For the conditions evaluated, the NRC-regulated landfill sites are equally, or more protective, than the Subtitle C landfills. Both EPA- and NRC-regulated facilities tend to be sited, on average, in fairly protective locations (based on distance to receptors, climate, and soils).

## 6.3 Results

Figures 6-2 through 6-7 provide the results of this analysis and are supported by Tables 6-2 through 6-5, which provide data collected and data sources. Significant comparisons are briefly discussed by data type below.

### 6.3.1 Distance to Receptor Well

The radial distance to wells downgradient from a landfill is an important parameter in calculating risk through the groundwater pathway. For the NRC-regulated commercial landfills, radial distances were estimated from site maps by measuring the distance from the planned mixed waste landfills to the nearest facility boundary (with the conservative assumption that a hypothetical residence with a well could be placed along the boundary) and by measuring the distance downgradient to the nearest town. In addition, some facility-specific documents provided distance to nearest receptor downgradient of the NRC landfills. Finally, EPA's Envirofacts system was used to obtain 1990 U.S. Census population data within 1-mile (1.6 km) and 5-mile (8 km) radii from the best available location.

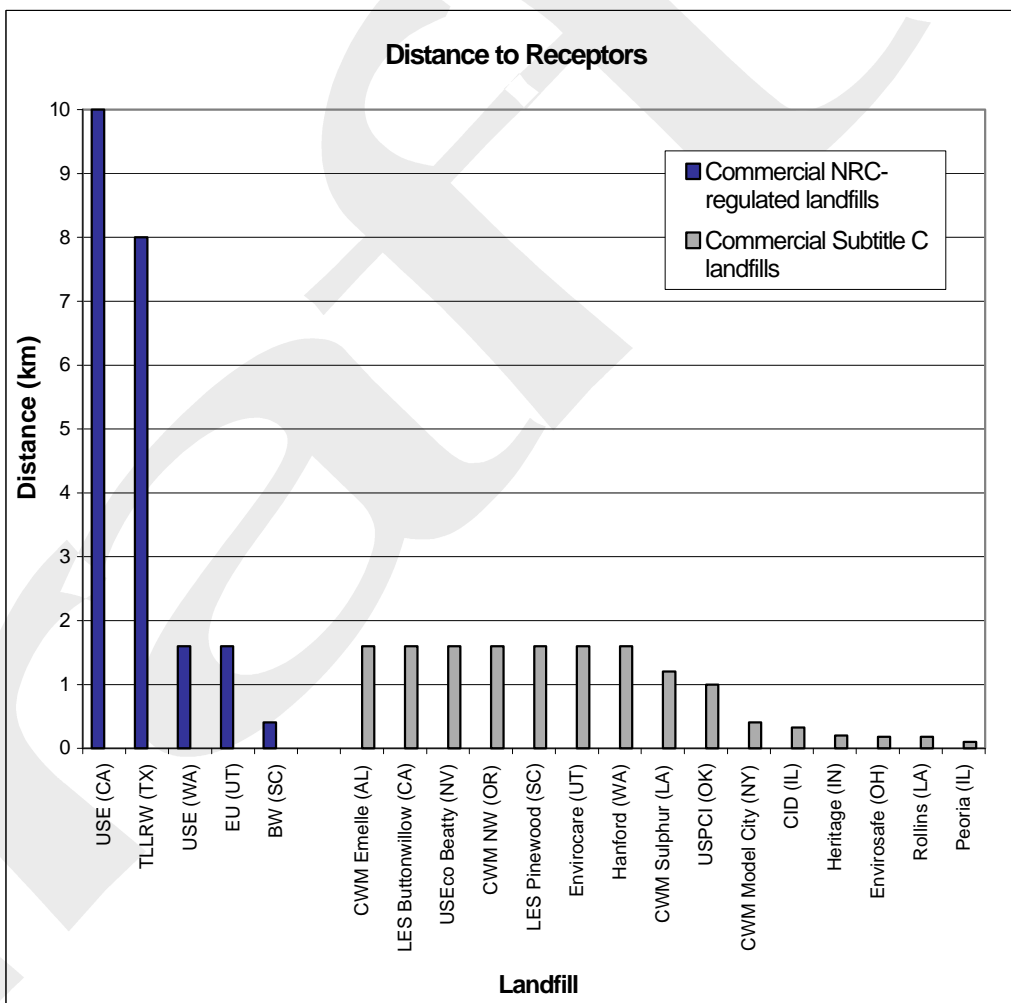
Because facility-specific documents were not readily available for the Subtitle C landfills, this population data analysis is limited to the Envirofacts data. Population density (within 1.6 km and 8 km radii) and land use maps were used to estimate minimum receptor well distances for 15 of the 19 hazardous waste disposal facilities. Data were not adequate to estimate distances for four Subtitle C facilities (CWM, Fort Wayne, LES Westmorland, Texas Eco, and USPCI UT), although all of these have residents within a 1-mile (1.6-km) radius of the site (see Table 6-2).

Results of this effort are tabulated in Table 6-2. Figure 6-2 shows that this parameter shows well distances are generally greater for four NRC facilities than for the Subtitle C sites. Receptor distances for the NRC-regulated sites and seven of the EPA-regulated sites are more than 1 kilometer or greater. This is significant because groundwater exposure modeling results

Site Name (State)	Minimum Distance to Nearest Receptor (km)
<b>Commercial NRC-regulated landfills</b>	
USE (CA)	> 10
TLLRW (TX)	> 8
USE (WA)	> 1.6
EU (UT)	> 1.6
BW (SC)	0.4 <sup>a</sup>
<b>Commercial EPA-regulated Subtitle C landfills</b>	
CWM Emelle (AL)	> 1.6
LES Buttonwillow (CA)	> 1.6
USEco Beatty (NV)	> 1.6
CWM NW (OR)	> 1.6
LES Pinewood (SC)	> 1.6
Envirocare (UT)	> 1.6
Hanford (WA)	> 1.6
CWM Sulphur (LA)	1.2
USPCI (OK)	1
CWM Model City (NY)	0.4
CID (IL)	0.32
Heritage (IN)	0.2
Envirosafe (OH)	0.18
Rollins (LA)	0.18
Peoria (IL)	0.1
CWM Fort Wayne (IN)	NA
LES Westmorland (CA)	NA
TexasEco (TX)	NA
USPCI (UT)	NA

<sup>a</sup> Hypothetical receptor (NUREG-0879), as cited in U.S. EPA (1998).

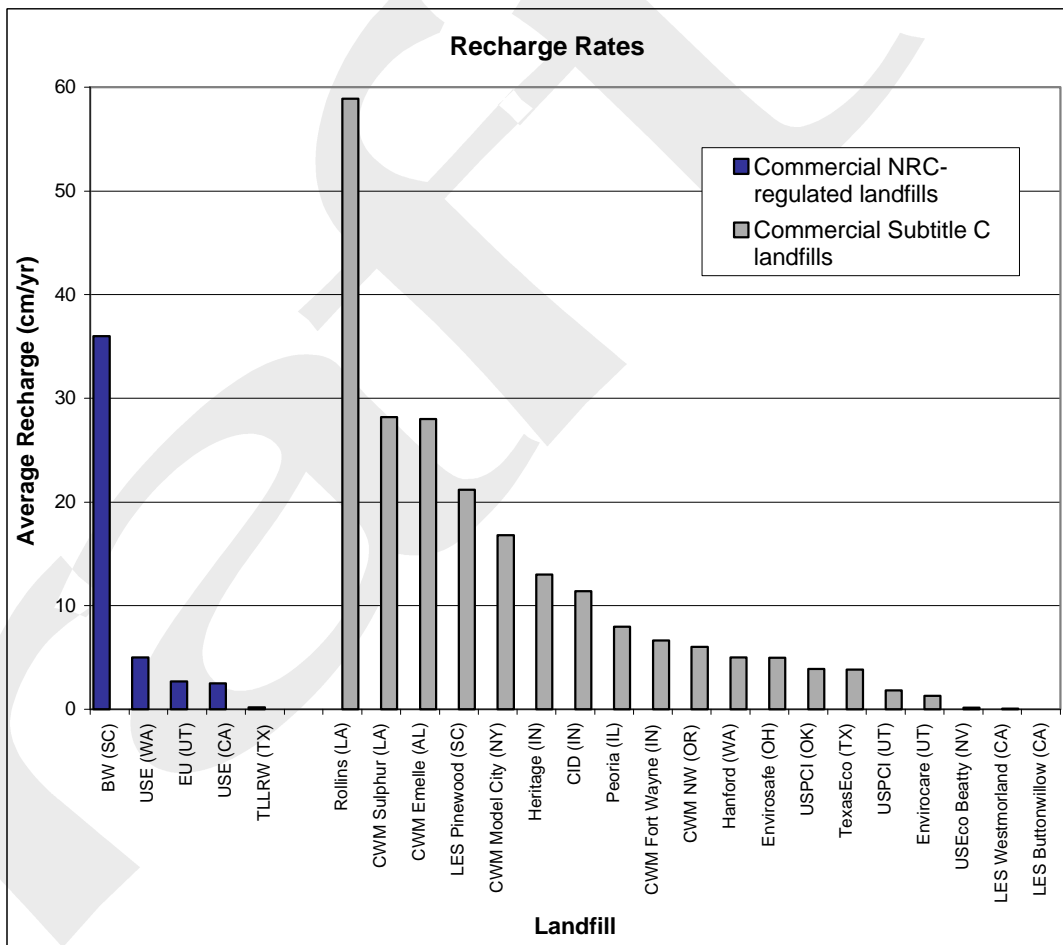
NA = Information not available.



**Figure 6-2. Distance to receptors: NRC and EPA-regulated Subtitle C commercial landfills.**

Site Name (State)	Average Recharge (cm/yr)
<b>Commercial NRC-regulated landfills</b>	
BW (SC)	36
USE (WA)	5
EU (UT)	2.7 <sup>a</sup>
USE (CA)	2.5 <sup>a</sup>
TLLRW (TX)	0.2
<b>Commercial EPA-regulated Subtitle C landfills</b>	
Rollins (LA)	58.9 <sup>a</sup>
CWM Sulphur (LA)	28.2 <sup>a</sup>
CWM Emelle (AL)	28 <sup>a</sup>
LES Pinewood (SC)	21.2 <sup>a</sup>
CWM Model City (NY)	16.8 <sup>a</sup>
Heritage (IN)	13 <sup>a</sup>
CID (IN)	11.4 <sup>a</sup>
Peoria (IL)	7.98 <sup>a</sup>
CWM Fort Wayne (IN)	6.63 <sup>a</sup>
CWM NW (OR)	6.02 <sup>a</sup>
Hanford (WA)	5
Envirosafe (OH)	4.95 <sup>a</sup>
USPCI (OK)	3.89 <sup>a</sup>
TexasEco (TX)	3.84 <sup>a</sup>
USPCI (UT)	1.85 <sup>a</sup>
Envirocare (UT)	1.3 <sup>a</sup>
USEco Beatty (NV)	0.18 <sup>a</sup>
LES Westmorland (CA)	0.03 <sup>a</sup>
LES Buttonwillow (CA)	< 0.005 <sup>a</sup>

<sup>a</sup> RTI estimate based on EPACMTP data (U.S. EPA, 1996).

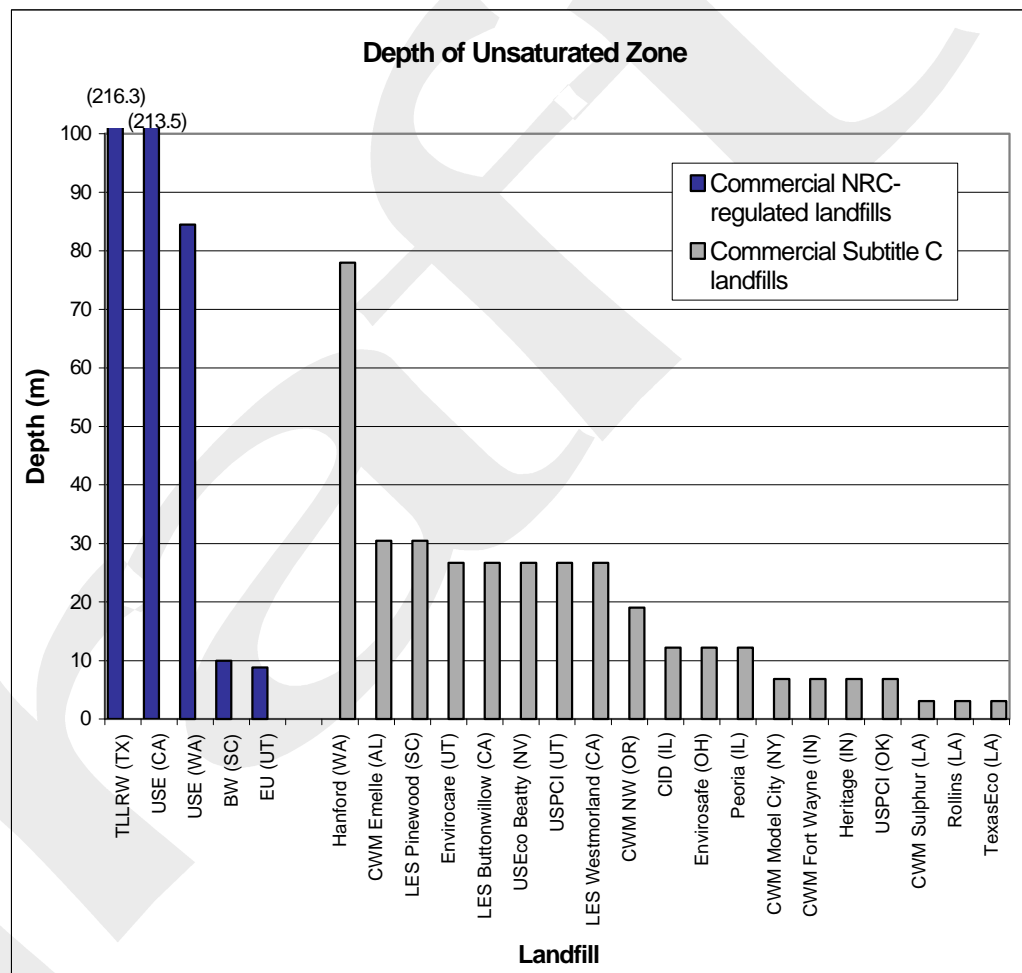


**Figure 6-3. Recharge rates: NRC and EPA-regulated Subtitle C commercial landfills.**

Site Name (State)	Unsaturated Zone Depth (m)
<b>Commercial NRC-regulated landfills</b>	
TLLRW (TX)	216.3
USE (CA)	213.5
USE (WA)	84.5
BW (SC)	10
EU (UT)	8.8 <sup>b</sup>
<b>Commercial EPA-regulated Subtitle C landfills</b>	
Hanford (WA)	78
CWM Emelle (AL)	> 30.48 <sup>a</sup>
LES Pinewood (SC)	> 30.48 <sup>a</sup>
Envirocare (UT)	26.67 <sup>a</sup>
LES Buttonwillow (CA)	26.67 <sup>a</sup>
USEco Beatty (NV)	26.67 <sup>a</sup>
USPCI (UT)	26.67 <sup>a</sup>
LES Westmorland (CA)	26.67 <sup>a</sup>
CWM NW (OR)	19.05 <sup>a</sup>
CID (IL)	12.19 <sup>a</sup>
Envirosafe (OH)	12.19 <sup>a</sup>
Peoria (IL)	12.19 <sup>a</sup>
CWM Model City (NY)	6.86 <sup>a</sup>
CWM Fort Wayne (IN)	6.86 <sup>a</sup>
Heritage (IN)	6.86 <sup>a</sup>
USPCI (OK)	6.86 <sup>a</sup>
CWM Sulphur (LA)	3.07 <sup>a</sup>
Rollins (LA)	3.07 <sup>a</sup>
TexasEco (LA)	3.07 <sup>a</sup>

<sup>a</sup> Mean DRASTIC values from EPA (1987). All except CWM Emmelle and LES Pinewood are average values.

<sup>b</sup> Depth to brine groundwater.

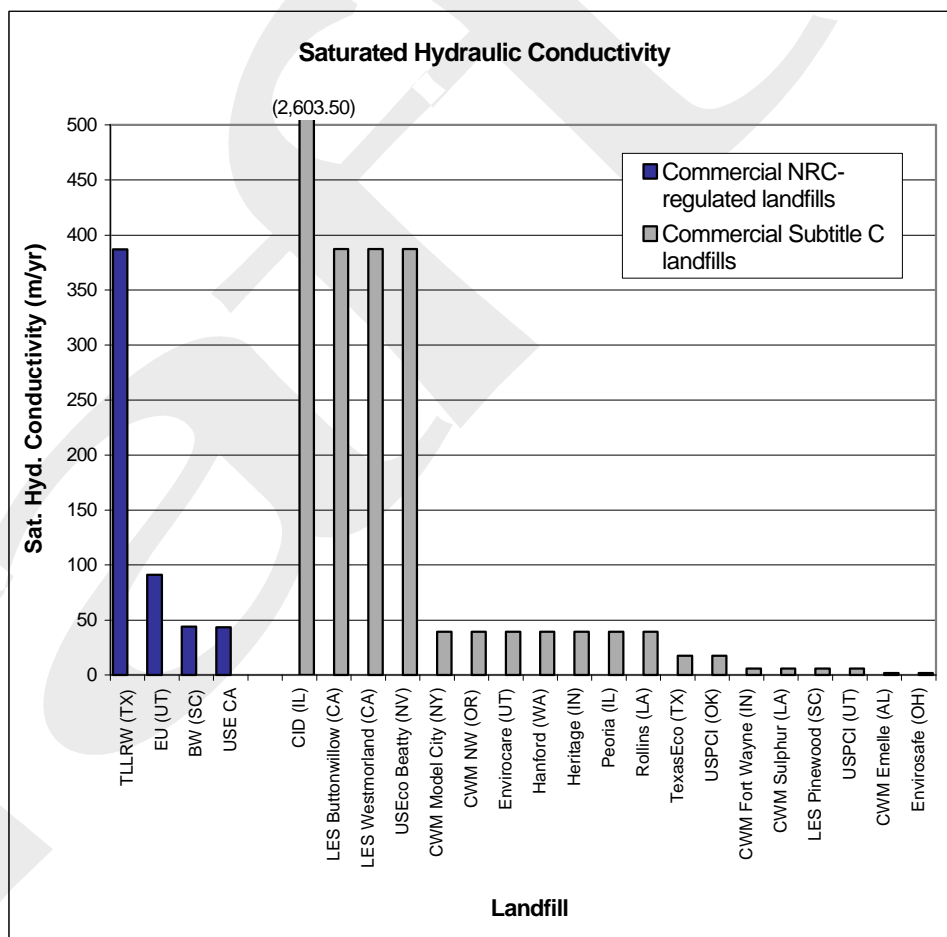


**Figure 6-4. Depth of the unsaturated zone. NRC and EPA-regulated Subtitle C commercial landfills.**

Site Name (State)	Saturated Hydraulic Conductivity (m/yr)
<b>Commercial NRC-regulated landfills</b>	
TLLRW (TX)	387.2 <sup>a</sup>
EU (UT)	91.1 <sup>a</sup>
BW (SC)	44.2
USE (CA)	43.4
USE (WA)	NA
<b>Commercial EPA-regulated Subtitle C landfills<sup>a</sup></b>	
CID (IL)	2,603.50
LES Buttonwillow (CA)	387.45
LES Westmorland (CA)	387.45
USEco Beatty (NV)	387.45
CWM Model City (NY)	39.44
CWM NW (OR)	39.44
Envirocare (UT)	39.44
Hanford (WA)	39.44
Heritage (IN)	39.44
Peoria (IL)	39.44
Rollins (LA)	39.44
TexasEco (TX)	17.53
USPCI (OK)	17.53
CWM Fort Wayne (IN)	6.13
CWM Sulphur (LA)	6.13
LES Pinewood (SC)	6.13
USPCI (UT)	6.13
CWM Emelle (AL)	1.75
Envirosafe (OH)	1.75

<sup>a</sup> RTI estimates (from soil texture relationship; Carsel and Parrish, 1988).

NA = Information not available.

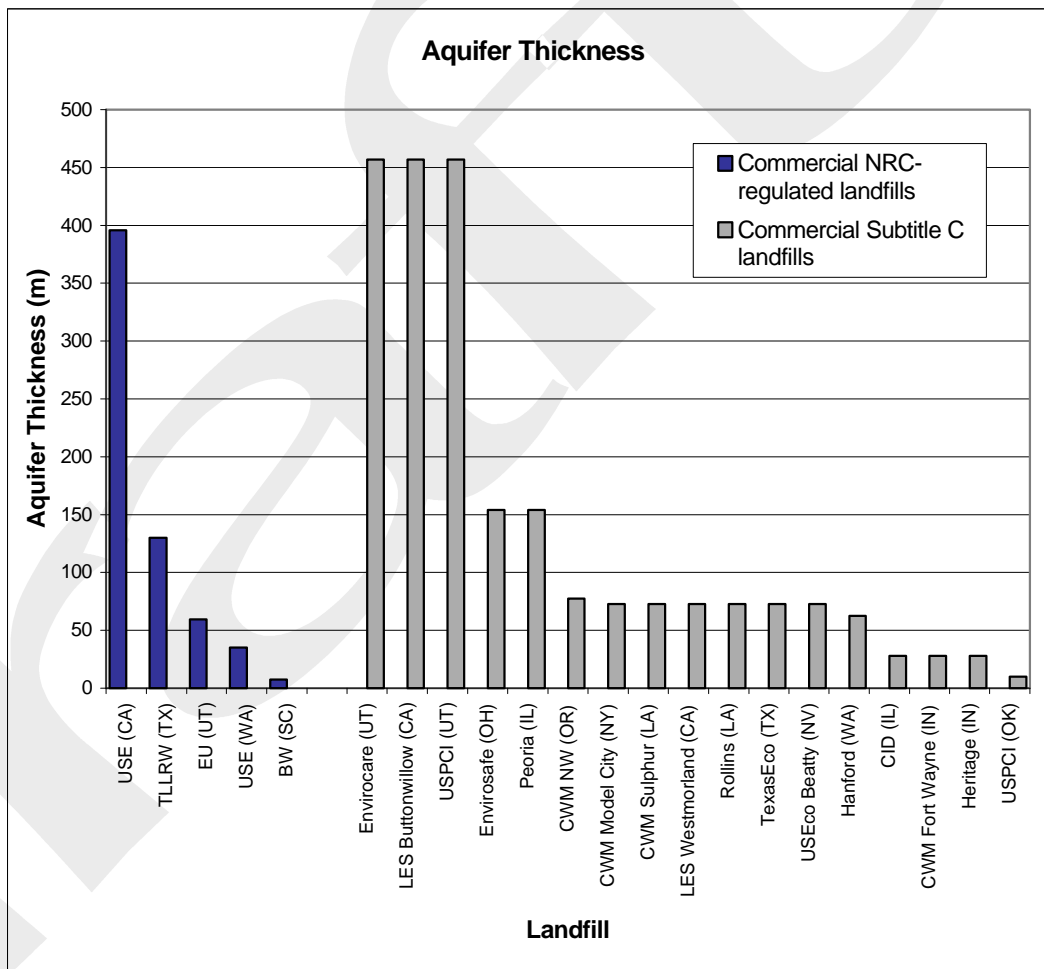


**Figure 6-5. Saturated hydraulic conductivity (unsaturated zone): NRC and EPA-regulated Subtitle C commercial landfills.**

Site Name (State)	Aquifer Thickness (m)
<b>Commercial NRC-regulated landfills</b>	
USE (CA)	396
TLLRW (TX)	130
EU (UT)	59.4
USE (WA)	35
BW (SC)	7.5
<b>Commercial EPA-regulated Subtitle C landfills</b>	
Envirocare (UT)	457 <sup>a</sup>
LES Buttonwillow (CA)	457 <sup>a</sup>
USPCI (UT)	457 <sup>a</sup>
Envirosafe (OH)	154 <sup>a</sup>
Peoria (IL)	154 <sup>a</sup>
CWM NW (OR)	77.5 <sup>a</sup>
CWM Model City (NY)	72.7 <sup>a</sup>
CWM Sulphur (LA)	72.7 <sup>a</sup>
LES Westmorland (CA)	72.7 <sup>a</sup>
Rollins (LA)	72.7 <sup>a</sup>
TexasEco (TX)	72.7 <sup>a</sup>
USEco Beatty (NV)	72.7 <sup>a</sup>
Hanford (WA)	62.5 <sup>a</sup>
CID (IL)	27.9 <sup>a</sup>
CWM Fort Wayne (IN)	27.9 <sup>a</sup>
Heritage (IN)	27.9 <sup>a</sup>
USPCI (OK)	10.1
LES Pinewood (SC)	NA
CWM Emelle (AL)	NA

<sup>a</sup> Estimates based on EPACMTP data (U.S. EPA, 1996).

NA = Information not available.



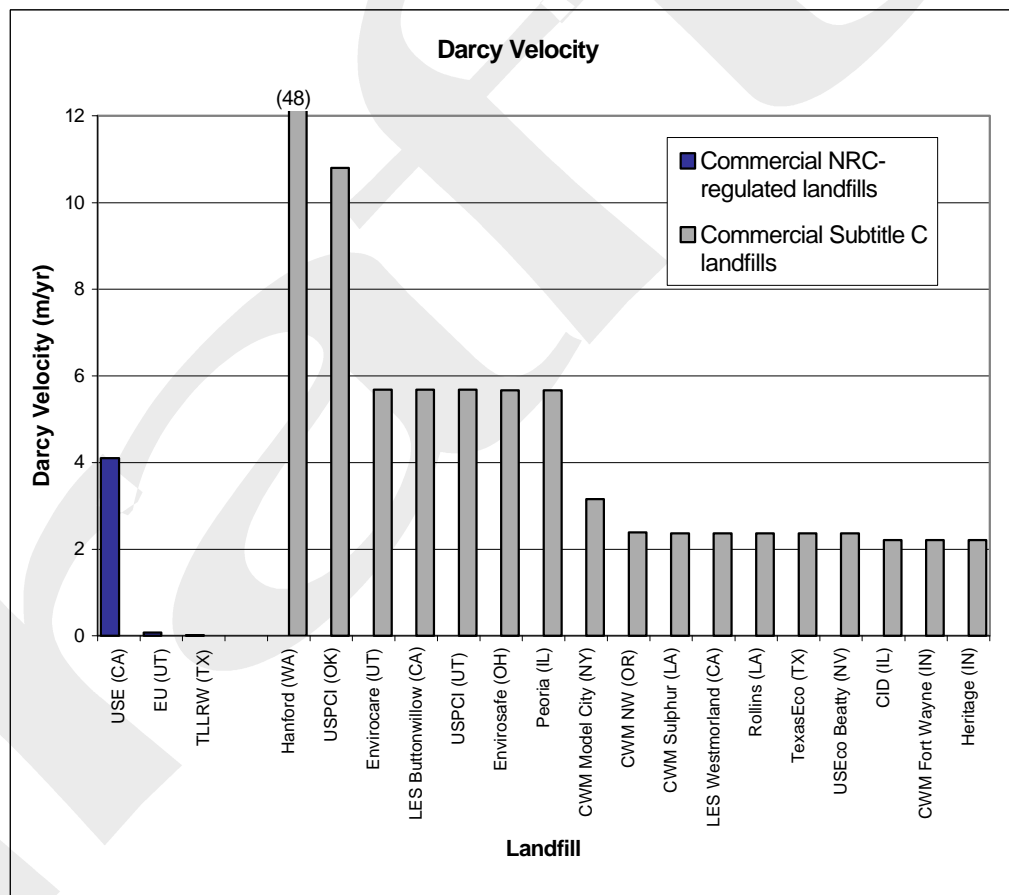
**Figure 6-6. Aquifer thickness: NRC and EPA-regulated Subtitle C commercial landfills.**

Site Name (State)	Darcy Velocity (m/yr) <sup>a</sup>
<b>Commercial NRC-regulated landfills</b>	
USE (CA)	4.1
EU (UT)	0.08
TLLRW (TX)	0.005
BW (SC)	NA
USE (WA)	NA
<b>Commercial EPA-regulated Subtitle C landfills <sup>b</sup></b>	
Hanford (WA)	48
USPCI (OK)	10.8
Envirocare (UT)	5.68
LES Buttonwillow (CA)	5.68
USPCI (UT)	5.68
Envirosafe (OH)	5.67
Peoria (IL)	5.67
CWM Model City (NY)	3.155
CWM NW (OR)	2.385
CWM Sulphur (LA)	2.3675
LES Westmorland (CA)	2.3675
Rollins (LA)	2.3675
TexasEco (TX)	2.3675
USEco Beatty (NV)	2.3675
CID (IL)	2.205
CWM Fort Wayne (IN)	2.205
Heritage (IN)	2.205
CWM Emelle (AL)	NA
LES Pinewood (SC)	NA

<sup>a</sup> Darcy Velocity = aquifer hydraulic conductivity (m/yr) x gradient.

<sup>b</sup> Estimates based on EPACMTP data (U.S. EPA, 1995).

NA = Information not available.



**Figure 6-7. Darcy velocity: NRC and EPA-regulated Subtitle C commercial landfills.**

**Table 6-2. Distance to Receptors: NRC and EPA-regulated Commercial Landfills**

		Receptor Information		
Site Name	Facility Area (km <sup>2</sup> )	Distance to Facility Boundary (minimum, m)	Distance to Receptors (km) (downgradient)	Population Density
<b>Commercial NRC-regulated Landfills</b>				
BW (SC)	NA	NA	0.40 km <sup>b</sup>	NA
EU (UT)	3	120 (EU, 1991)	52 km to Wendover, UT	0 residents within 1.6-km radius <sup>a</sup>
TLLRW (TX)	3,110	150 (TLLRWDA, 1995)	45 km to Van Horn, TX (TLLRWDA, 1995)	0 residents within 8-km radius <sup>a</sup>
USE (CA)	3	115 (USE, 1990)	95 km to Danby Lake, CA	0 residents within 10 km (USE, 1990)
USE (WA)	1,500 <sup>c</sup>	NA	3 to 5 km <sup>c</sup>	NA
<b>Commercial EPA-regulated Landfills</b>				
CID (IL)	NA	NA	0.32 km minimum <sup>d</sup>	6,381 residents within 1.6 km; avg pop dens per sq mi = 2,031
CWM Emelle (AL)	NA	NA	1.6 km minimum	0 residents within 1.6 km
CWM Fort Wayne (IN)	NA	NA	NA	855 residents within 1.6 km; avg pop dens per sq mi = 272
CWM Model City (NY)	NA	NA	0.40 km minimum <sup>d</sup>	233 residents within 1.6 km; avg pop dens per sq mi = 74
CWM NW (OR)	NA	NA	1.6 km minimum	0 residents within 1.6 km
CWM Sulphur (LA)	NA	NA	1.2 km minimum <sup>d</sup>	24 residents within 1.6 km; avg pop dens per sq mi = 7
Envirocare (UT)			1.6 km minimum	0 residents within 1.6 km
Envirosafe (OH)	NA	NA	0.18 km minimum (distance to non- industrial land use)	1,721 residents within 1.6 km; avg pop dens per sq mi = 547
Hanford (WA)	NA	NA	1.6 km minimum	0 residents within 1.6 km
Heritage (IN)	NA	NA	0. 2 km minimum <sup>d</sup>	17 residents within 1.6 km; avg pop dens per sq mi = 5
LES Buttonwillow (CA)	NA	NA	1.6 km minimum	0 residents within 1.6 km
LES Pinewood (SC)	NA	NA	1.6 km minimum	1 resident within 1.6 km
LES Westmoreland (CA)	NA	NA	NA	26 residents within 1.6 km avg pop dens per sq mi = 8

(continued)

Table 6-2. (continued)

		Receptor Information		
Site Name	Facility Area (km <sup>2</sup> )	Distance to Facility Boundary (minimum, m)	Distance to Receptors (km) (downgradient)	Population Density
Commercial EPA-regulated Landfills (continued)				
Peoria (IL)	NA	NA	0.1 km minimum (distance to non-industrial land use)	2,534 residents within 1.6 km; avg pop dens per sq mi = 806
Rollins (LA)	NA	NA	0.18 km minimum (distance to non-industrial land use)	419 residents within 1.6 km; avg pop dens per sq mi = 133
TexasEco (TX)	NA	NA	NA	26 residents within 1.6 km; avg pop dens per sq mi = 8
USEco Beatty (NV)	NA	NA	1.6 km minimum	0 residents within 1.6 km
USPCI (OK)	NA	NA	assume 1 km minimum distance	4 residents within 1.6 km; avg pop dens per sq mi = 1
USPCI (UT)	NA	NA	NA	2,166 residents within 1.6 km; avg pop dens per sq mi = 689

NA = Not available.

<sup>a</sup> 1990 U.S. Census data from query on latitude/longitude, EPA Envirofacts system.

<sup>b</sup> “Hypothetical” receptor; NUREG-0879 (1990), as cited in U.S. EPA (1998).

<sup>c</sup> DOE/EIS-01113 (1987), as cited in U.S. EPA (1998).

<sup>d</sup> Estimate based on Envirofacts population density and land use.

**Table 6-3. Annual Climate Parameters: NRC and EPA-Regulated Subtitle C Commercial Landfills**

Site Name	Temperature (°F)	Precipitation (cm)	Recharge <sup>a</sup> (cm)
<b>Commercial NRC-Regulated Landfills</b>			
BW <sup>b</sup>	Annual mean 64 (U.S. EPA, 1998); 62.76 (HWIR, 1999)	Annual mean 117 (U.S. EPA, 1998); 125.94 (HWIR, 1999)	36 (U.S. EPA, 1998); > 25 (DRASTIC); 35.6 in Watkinsville, GA (EPACMTP);
EU	Summer 63.9, Winter 36.9 (EU, 1991); 52.02 (HWIR, 1999)	30.2 (EU, 1991); 40.1 (HWIR, 1999)	0 - 5 (DRASTIC); 2.7 in Salt Lake City, UT (EPACMTP)
TLLRW	Summer 80, Winter 48 (TLLRWDA, 1995); 63.61 (HWIR, 1999)	32 (TLLRWDA, 1995); 22.87 (HWIR, 1999)	0.2 (TLLRWDA, 1995); 0 - 5 (DRASTIC); 0.8 in El Paso, TX (EPACMTP)
USE CA	Summer 95, Winter 52 (USE, 1990); 67.84 (HWIR, 1999)	< 12.7 (USE, 1990); 9.85 (HWIR, 1999)	0 - 5 (DRASTIC); 7 in Los Angeles, CA (EPACMTP)
USE WA <sup>c</sup>	Annual range 29 - 76 (U.S. EPA, 1998); 52.14 (HWIR, 1999)	28.44 (HWIR, 1999)	0.5 - 5 (U.S. EPA, 1998); 5 - 10 (DRASTIC); <0.005 (EPACMTP);
<b>Commercial EPA-Regulated Subtitle C Landfills</b>			
CID	49.44 (HWIR, 1999)	87.65 (HWIR, 1999)	10 - 18 (DRASTIC); 11.4 (EPACMTP)
CWM Emelle	63.64 (HWIR, 1999)	148.91 (HWIR, 1999)	0 - 5 (DRASTIC); 28 (EPACMTP)
CWM Fort Wayne	52.23 (HWIR, 1999)	93.31 (HWIR, 1999)	10 - 18 (DRASTIC); 6.63 (EPACMTP)
CWM Model City	47.55 (HWIR, 1999)	97.95 (HWIR, 1999)	10 - 18 (DRASTIC); 16.8 (EPACMTP)
CWM NW	52.14 (HWIR, 1999)	28.44 (HWIR, 1999)	5 - 10 (DRASTIC); 6.02 (EPACMTP)
CWM Sulphur	67.03 (HWIR, 1999)	142.27 (HWIR, 1999)	25+ (DRASTIC); 28.2 (EPACMTP)
Envirocare	52.02 (HWIR, 1999)	40.1 (HWIR, 1999)	0 - 5 (DRASTIC); 1.3 (EPACMTP)
Envirosafe	49.84 (HWIR, 1999)	94.85 (HWIR, 1999)	10 - 18 (DRASTIC); 4.95 (EPACMTP)
Hanford	52.14 (HWIR, 1999)	28.44 (HWIR, 1999)	5 (DOE, 1996); 5 - 10 (DRASTIC); 0.03 (EPACMTP)
Heritage	52.16 (HWIR, 1999)	104.82 (HWIR, 1999)	10 - 18 (DRASTIC); 13 (EPACMTP)
LES Buttonwillow	59.54 (HWIR, 1999)	47.27 (HWIR, 1999)	0 - 5 (DRASTIC); <0.005 (EPACMTP)
LES Pinewood	62.76 (HWIR, 1999)	125.94 (HWIR, 1999)	0 - 5 (DRASTIC); 21.2 (EPACMTP)
LES Westmorland	68.81 (HWIR, 1999)	30.39 (HWIR, 1999)	0 - 5 (DRASTIC); 0.03 (EPACMTP)
Peoria	50.5 (HWIR, 1999)	89.28 (HWIR, 1999)	10 - 18 (DRASTIC); 7.98 (EPACMTP)
Rollins	66.94 (HWIR, 1999)	157.74 (HWIR, 1999)	25+ (DRASTIC); 58.9 (EPACMTP)
TexasEco	68.07 (HWIR, 1999)	112.59 (HWIR, 1999)	25+ (DRASTIC); 3.84 (EPACMTP)
USEco Beatty	67.84 (HWIR, 1999)	9.85 (HWIR, 1999)	0 - 5 (DRASTIC); 0.18 (EPACMTP)
USPCI OK	59.94 (HWIR, 1999)	89.86 (HWIR, 1999)	10 - 18 (DRASTIC); 3.89 (EPACMTP)
USPCI UT	52.02 (HWIR, 1999)	40.1 (HWIR, 1999)	0 - 5 (DRASTIC); 1.85 (EPACMTP)

<sup>a</sup> DRASTIC values from U.S. EPA (1987); EPACMTP values from U.S. EPA (1996).

<sup>b</sup> Information from NUREG-0879 (1990), as cited in U.S. EPA (1998).

<sup>c</sup> Information from DOE/EIS-01113 (1987), as cited in U.S. EPA (1998).

**Table 6-4. Unsaturated Zone (Soil) Variables: NRC and EPA-Regulated Subtitle C Commercial Landfills**

Site Name	Soil Type/ Texture	Saturated Hydraulic Conductivity (m/y)	Moisture Retention Parameter, alpha (1/cm)	Moisture Retention Parameter, beta (unitless)	Residual Water Content (cm <sup>3</sup> /cm <sup>3</sup> )	Saturated Water Content/ Porosity (cm <sup>3</sup> /cm <sup>3</sup> )	Depth of Unsaturated Zone (m)	Bulk Density (g/cm <sup>3</sup> )	Fraction Organic Matter (g/g)	pH	Annual Average Moisture Content (unitless)
<b>Commercial NRC-regulated Landfills</b>											
BW (SC) <sup>d</sup>	Sandy clay	44.2	0.12 <sub>b</sub>	1.23 <sub>b</sub>	0.100 <sub>b</sub>	0.4	9 - 11	NA	NA	NA	NA
EU (UT)	Loam <sup>a</sup>	91.1 <sub>b</sub>	0.036 <sub>b</sub>	1.56 <sub>b</sub>	0.02 (EU, 1991)	0.43 <sub>b</sub> ; 0.42 (EU, 1991)	8.8 (EU, 1991) <sup>c</sup>	1.51 <sub>a</sub>	0.8 <sub>a</sub>	8.63 <sub>a</sub>	NA
TLLRW (TX)	Sandy and clay loam (TLLRWDA, 1995)	387.2 <sub>b</sub>	0.075 <sub>b</sub>	1.89 <sub>b</sub>	0.065 <sub>b</sub>	0.45 average (TLLRWDA, 1995)	203.5 - 229 (TLLRWDA, 1995)	1.56 <sup>a</sup>	0.4 <sub>a</sub>	8.15 <sub>a</sub>	NA
USE (CA)	Sand and silt or clayey sand (USE, 1990)	43.4 (USE, 1990)	0.036 <sub>b</sub>	1.56 <sub>b</sub>	0.078 <sub>b</sub>	0.43 <sub>b</sub> ; 0.21 - 0.34 (USE, 1990)	198 - 229 (USE, 1990)	1.51 <sup>a</sup>	0.2 <sub>a</sub>	8.23 <sub>a</sub>	NA
USE (WA) <sup>e</sup>	---	NA	NA	NA	NA	NA	61 - 108	NA	NA	NA	NA
<b>Commercial EPA-regulated Subtitle C Landfills</b>											
CID (IL)	Sand	2603.50 <sup>b</sup>	0.145 <sub>b</sub>	2.68 <sub>b</sub>	0.045 <sub>b</sub>	0.43 <sub>b</sub>	9.14-15.24 <sub>f</sub>	1.51 <sub>a</sub>	0.004 <sub>a</sub>	6.1 <sub>a</sub>	NA
CWM Emelle (AL)	Silty clay	1.75 <sup>b</sup>	0.005 <sub>b</sub>	1.09 <sub>b</sub>	0.07 <sub>b</sub>	0.36 <sub>b</sub>	30.48 <sub>f</sub>	1.70 <sub>a</sub>	0.005 <sub>a</sub>	6.9 <sub>a</sub>	NA
CWM Fort Wayne (IN)	Silty clay loam	6.13 <sup>b</sup>	0.01 <sub>b</sub>	1.23 <sub>b</sub>	0.089 <sub>b</sub>	0.43 <sub>b</sub>	4.57-9.14 <sub>f</sub>	1.51 <sub>a</sub>	0.024 <sub>a</sub>	7.0 <sub>a</sub>	NA
CWM Model City (NY)	Silt loam	39.44 <sup>b</sup>	0.02 <sub>b</sub>	1.41 <sub>b</sub>	0.067 <sub>b</sub>	0.45 <sub>b</sub>	4.57-9.14 <sub>f</sub>	1.46 <sub>a</sub>	0.01 <sub>a</sub>	6.9 <sub>a</sub>	NA
CWM NW (OR)	Silt loam	39.44 <sup>b</sup>	0.02 <sub>b</sub>	1.41 <sub>b</sub>	0.067 <sub>b</sub>	0.45 <sub>b</sub>	15.24-22.86 <sub>f</sub>	1.46 <sub>a</sub>	0.007 <sub>a</sub>	7.6 <sub>a</sub>	NA
CWM Sulphur (LA)	Silty clay loam	6.13 <sup>b</sup>	0.01 <sub>b</sub>	1.23 <sub>b</sub>	0.089 <sub>b</sub>	0.43 <sub>b</sub>	1.52-4.57 <sub>f</sub>	1.51 <sub>a</sub>	0.007 <sub>a</sub>	6.6 <sub>a</sub>	NA
Envirocare ((UT)	Silt loam	39.44 <sup>b</sup>	0.02 <sub>b</sub>	1.41 <sub>b</sub>	0.067 <sub>b</sub>	0.45 <sub>b</sub>	22.86-30.48 <sub>f</sub>	1.46 <sub>a</sub>	0.003 <sub>a</sub>	8.5 <sub>a</sub>	NA
Envirosafe (OH)	Silty clay	1.75 <sup>b</sup>	0.005 <sub>b</sub>	1.09 <sub>b</sub>	0.07 <sub>b</sub>	0.36 <sub>b</sub>	9.14-15.24 <sub>f</sub>	1.70 <sub>a</sub>	0.07 <sub>a</sub>	7.1 <sub>a</sub>	NA
Hanford (WA)	Silt loam	39.44 <sup>b</sup>	0.02 <sub>b</sub>	1.41 <sub>b</sub>	0.067 <sub>b</sub>	0.45 <sub>b</sub>	56 - 100 (DOE, 1996); 15.24-22.86 <sub>f</sub>	1.46 <sup>a</sup>	0.003 <sub>a</sub>	8.0 <sub>a</sub>	NA
Heritage (IN)	Silt loam	39.44 <sup>b</sup>	0.02 <sub>b</sub>	1.41 <sub>b</sub>	0.067 <sub>b</sub>	0.45 <sub>b</sub>	4.57-9.14 <sub>f</sub>	1.46 <sub>a</sub>	0.019 <sub>s</sub>	7.1 <sub>s</sub>	NA
LES Buttonwillow (CA)	Sandy loam	387.45 <sup>b</sup>	0.075 <sub>b</sub>	1.89 <sub>b</sub>	0.065 <sub>b</sub>	0.41 <sub>b</sub>	22.86-30.48 <sub>f</sub>	1.56 <sub>a</sub>	0.002 <sub>a</sub>	7.8 <sub>a</sub>	NA
LES Pinewood (SC)	Silty clay loam	6.13 <sup>b</sup>	0.01 <sub>b</sub>	1.23 <sub>b</sub>	0.089 <sub>b</sub>	0.43 <sub>b</sub>	30.48 <sub>f</sub>	1.51 <sub>a</sub>	0.025 <sub>a</sub>	5.3 <sub>a</sub>	NA
LES Westmorland (CA)	Sandy loam	387.45 <sup>b</sup>	0.075 <sub>b</sub>	1.89 <sub>b</sub>	0.065 <sub>b</sub>	0.41 <sub>b</sub>	22.86-30.48 <sub>f</sub>	1.56 <sub>a</sub>	0.001 <sub>a</sub>	8.1 <sub>a</sub>	NA
Peoria (IL)	Silt loam	39.44 <sup>b</sup>	0.002 <sub>b</sub>	1.41 <sub>b</sub>	0.067 <sub>b</sub>	0.45 <sub>b</sub>	9.14-15.24 <sub>f</sub>	1.46 <sub>a</sub>	0.012 <sub>a</sub>	6.4 <sub>a</sub>	NA
Rollins (LA)	Silt loam	39.44 <sup>b</sup>	0.02 <sub>b</sub>	1.41 <sub>b</sub>	0.067 <sub>b</sub>	0.45 <sub>b</sub>	1.52-4.57 <sub>f</sub>	1.46 <sub>a</sub>	0.006 <sub>a</sub>	5.6 <sub>a</sub>	NA

(continued)

Table 6-4. (continued)

Site Name	Soil Type/ Texture	Saturated Hydraulic Conductivity (m/y)	Moisture Retention Parameter, alpha (1/cm)	Moisture Retention Parameter, beta (unitless)	Residual Water Content (cm <sup>3</sup> /cm <sup>3</sup> )	Saturated Water Content/ Porosity (cm <sup>3</sup> /cm <sup>3</sup> )	Depth of Unsaturated Zone (m)	Bulk Density (g/cm <sup>3</sup> )	Fraction Organic Matter (g/g)	pH	Annual Average Moisture Content (unitless)
TexasEco (TX)	Clay	17.53 <sup>b</sup>	0.008 <sup>b</sup>	1.09 <sup>b</sup>	0.068 <sup>b</sup>	0.38 <sup>b</sup>	1.52-4.57 <sup>f</sup>	1.64 <sup>a</sup>	0.006 <sup>a</sup>	8.1 <sup>a</sup>	NA
USEco Beatty (NV)	Sandy loam	387.45 <sup>b</sup>	0.075 <sup>b</sup>	1.89 <sup>b</sup>	0.065 <sup>b</sup>	0.41 <sup>b</sup>	22.86-30.48 <sup>f</sup>	1.56 <sup>a</sup>	0.001 <sup>a</sup>	8.4 <sup>a</sup>	NA
USPCI (OK)	Clay	17.53 <sup>b</sup>	0.008 <sup>b</sup>	1.09 <sup>b</sup>	0.068 <sup>b</sup>	0.38 <sup>b</sup>	4.57-9.14 <sup>f</sup>	1.64 <sup>a</sup>	0.004 <sup>a</sup>	8.0 <sup>a</sup>	NA
USPCI (UT)	Silty clay loam	6.13 <sup>b</sup>	0.01 <sup>b</sup>	1.23 <sup>b</sup>	0.089 <sup>b</sup>	0.43 <sup>b</sup>	22.86-30.48 <sup>f</sup>	1.51 <sup>a</sup>	0.009 <sup>a</sup>	7.7 <sup>a</sup>	NA

NA = Not available.

<sup>a</sup> Property of entire soil column based on map units from STATSGO database (1998).

<sup>b</sup> Mean value from soil texture obtained from Carsel and Parrish (1998).

<sup>c</sup> Depth to brine groundwater.

<sup>d</sup> All information from NUREG-0879 (1990), as cited in U.S. EPA (1998), unless indicated otherwise.

<sup>e</sup> All information from DOE/EIS-01113 (1987), as cited in U.S. EPA (1998).

<sup>f</sup> DRASTIC values from U.S. EPA (1987).

*Italics indicate RTI estimates using HWIR data collection methodologies (HWIR, 1999).*

**Table 6-5. Aquifer Parameters: NRC- and EPA-Regulated Subtitle C Commercial Landfills**

Site Name	EPACMTP Aquifer Type (Ind. D Landfills: No., %)	Porosity	Bulk Density (g/cm <sup>3</sup> )	Aquifer Thickness (m)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient	Darcy Velocity (m/yr) <sup>e</sup>	Seepage Velocity (m/yr)	pH	Ground-water Flow Direction
<b>Commercial NRC-regulated Landfills</b>										
BW (SC) <sup>a</sup>	Unconsolidated & Semiconsolidated Shallow Aquifers (1, 0.1%)	0.4	"dense"	6 - 9	3.2 x 10 <sup>5</sup>	NA	NA	2.2	NA	NA
EU (UT)	Alluvial Basins, Valleys and Fans (83, 11%)	NA	NA	59.4 (EU, 1991)	NA	0.0002 (EU, 1991)	0.08 avg. (EU, 1991)	2.7 (EU, 1991)	NA	N
TLLRW (TX)	Alluvial Basins, Valleys and Fans (83, 11%)	NA	NA	110 - 150 (TLLRWDA, 1995)	0.7 - 12.8 (TLLRWDA, 1995)	0.0005 (TLLRWDA, 1995)	0.003 - 0.006 calculated (TLLRWDA, 1995)	0.5 (TLLRWDA, 1995)	NA	W, NW
USE (CA)	Alluvial Basins, Valleys and Fans (83, 11%)	0.1 estimated (USE, 1990)	NA	396 (USE, 1990)	137 (USE, 1990)	0.03 (USE, 1990)	4.1 calculated (USE, 1990)	0.2 - 8 (USE, 1990)	NA	S
USE (WA) <sup>b</sup>	Metamorphic and Igneous (63, 8%)	NA	NA	0 - 70	NA	NA	NA	NA	NA	NA
<b>Commercial EPA-regulated Subtitle C Landfills <sup>c</sup></b>										
CID (IL)	Till and Till Over Outwash (14, 2%)	NA	NA	0.914 - 54.9	9.46 - 21,800	4.0×10 <sup>-8</sup> - 0.05	2.205	NA	NA	NA
CWM Emelle (AL)	NA <sup>d</sup>	NA	NA	NA	NA	NA	NA	NA	NA	NA
CWM Fort Wayne (IN)	Till and Till Over Outwash (14, 2%)	NA	NA	0.914 - 54.9	9.46 - 21,800	4.0×10 <sup>-8</sup> - 0.05	2.205	NA	NA	NA
CWM Model City (NY)	Sand and Gravel (223, 28%)	NA	NA	0.332 - 145	3.15 - 116,000	1.0×10 <sup>-7</sup> - 0.092	3.155	NA	NA	NA
CWM NW (OR)	Metamorphic and Igneous (63, 8%)	NA	NA	3.05 - 152	3.15 - 11,000	7.0×10 <sup>-6</sup> - 0.1	2.385	NA	NA	NA
CWM Sulphur (LA)	Sand and Gravel (223, 28%)	NA	NA	0.332 - 145	3.15 - 116,000	1.0×10 <sup>-7</sup> - 0.092	2.3675	NA	NA	NA
Envirocare (UT)	Alluvial Basins, Valleys and Fans (83, 11%)	NA	NA	0.305 - 914	3.15 - 3,190,000	2.0×10 <sup>-6</sup> - 0.093	5.68	NA	NA	NA
Envirosafe (OH)	Solution Limestone (154, 19%)	NA	NA	3.05 - 305	94.6 - 158,000	2.0×10 <sup>-6</sup> - 0.093	5.67	NA	NA	NA
Hanford (WA)	Outwash (32, 4%)	NA	NA	3.05 - 122	473 - 110,000	8.0×10 <sup>-7</sup> - 0.075	48	NA	NA	NA
Heritage (IN)	Till and Till Over Outwash (14, 2%)	NA	NA	0.914 - 54.9	9.46 - 21,800	4.0×10 <sup>-8</sup> - 0.05	2.205	NA	NA	NA
LES Buttonwillow (CA)	Alluvial Basins, Valleys and Fans (83, 11%)	NA	NA	0.305 - 914	3.15 - 3,190,000	2.0×10 <sup>-6</sup> - 0.093	5.68	NA	NA	NA
LES Pinewood (SC)	NA <sup>d</sup>	NA	NA	NA	NA	NA	NA	NA	NA	NA
LES Westmorland (CA)	Sand and Gravel (223, 28%)	NA	NA	0.332 - 145	3.15 - 116,000	1.0×10 <sup>-7</sup> - 0.092	2.3675	NA	NA	NA
Peoria (IL)	Solution Limestone (154, 19%)	NA	NA	3.05 - 305	94.6 - 158,000	2.0×10 <sup>-6</sup> - 0.033	5.67	NA	NA	NA

(continued)

Table 6-5 (continued)

Site Name	EPACMTP Aquifer Type (Ind. D Landfills: No., %)	Porosity	Bulk Density (g/cm <sup>3</sup> )	Aquifer Thickness (m)	Hydraulic Conductivity (m/yr)	Hydraulic Gradient	Darcy Velocity (m/yr) <sup>e</sup>	Seepage Velocity (m/yr)	pH	Ground- water Flow Direction
Rollins (LA)	Sand and Gravel (223, 28%)	NA	NA	0.332 - 145	3.15 - 116,000	$1.0 \times 10^{-7}$ - 0.092	2.3675	NA	NA	NA
TexasEco (TX)	Sand and Gravel (223, 28%)	NA	NA	0.332 - 145	3.15 - 116,000	$1.0 \times 10^{-7}$ - 0.092	2.3675	NA	NA	NA
USEco Beatty (NV)	Sand and Gravel (223, 28%)	NA	NA	0.332 - 145	3.15 - 116,000	$1.0 \times 10^{-7}$ - 0.092	2.3675	NA	NA	NA
USPCI (OK)	Other (Not Classifiable) (74, 9%)	NA	NA	10.1	1,890	0.0057	10.8	NA	NA	NA
USPCI (UT)	Alluvial Basins, Valleys and Fans (83, 11%)	NA	NA	0.305 - 914	3.15 - 3,190,000	$2.0 \times 10^{-6}$ - 0.093	6.03	NA	NA	NA

NA = Not available.

<sup>a</sup> All information from NUREG-0879 (1990), as cited in U.S. EPA (1998).

<sup>b</sup> All information from DOE/EIS-01113, as cited in U.S. EPA (1998).

<sup>c</sup> All information from EPACMTP (U.S.EPA, 1996).

<sup>d</sup> No suitable EPACMTP aquifer type.

<sup>e</sup> Median values used, except where noted.

are very sensitive to receptor well distance. The remaining eight EPA-regulated landfills for which receptor distances can be estimated show lower distances, with three (Envirosafe, OH, Peoria, IL, and Rollins, LA) having minimum distance estimates of 200 meters or less. However, the estimates for these eight facilities are most likely conservative (i.e., based on population density data alone) and should be confirmed with more detailed site-specific information.

### 6.3.2 Recharge Rates

Climatic data (temperature, precipitation, and recharge) are shown in Table 6-3, with Subtitle C and NRC site recharge rates compared in Figure 6-3. Because recharge rates are dependent upon both precipitation data, evaporation rates, and soil characteristics, the comparison in Figure 6-3 represents a comparison of both climatic and soils data for the sites in question.

Recharge estimates were compiled from the DRASTIC manual (U.S. EPA, 1987) and HELP-calculated values from EPACMTP (U.S. EPA, 1996). To assign the EPACMTP data to the Subtitle C and NRC sites, the climate and groundwater classes for each site were determined by correlating each facility with nearby Industrial D sites from EPACMTP. Site-specific estimates were also available for three NRC-regulated facilities: (BW [U.S. EPA, 1998], TLLRW [TLLRWDA, 1995], and USE WA [U.S. EPA, 1998]). In most cases, a good agreement can be seen between sources (see Table 6-3).

Many of the Subtitle C and NRC sites have relatively low recharge rates (less than 10 cm/yr). This is due in part to the low precipitation rates characteristic of many NRC and Subtitle C sites. Low-permeability soils also contribute to the lower recharge for several of the Subtitle C sites (e.g., CID, IN, Peoria, IL, and Envirosafe, OH).

### 6.3.3 Soil Parameters

Soil hydrologic properties and other unsaturated zone variables were available from site-specific documents for the NRC-regulated commercial landfills. Where data were not available, geographic information system (GIS)-based methods were used to collect predominant soil properties for a 1-km radius around each facility (HWIR, 1999). Table 6-4 shows the results of this data collection effort. In general, soil properties were similar for the NRC- and EPA-regulated facilities, but several of the Subtitle C sites had less permeable soils. Two of the most important parameters in terms of impact on model results (depth-to-water and hydraulic conductivity) are discussed below.

**6.3.3.1 Depth of Unsaturated Zone.** Unsaturated zone depth (depth to groundwater) is generally greater for the NRC-regulated sites than for the EPA-regulated sites (Figure 6-4, Table 6-4). However, the Subtitle C estimates are uncertain because site-specific data were not readily available. Differences between the NRC- and EPA-regulated sites in proximity to each other suggest that the median DRASTIC (U.S. EPA, 1987) setting estimates used in this analysis may significantly underestimate unsaturated zone depth, at least for the Subtitle C sites in the western United States.

**6.3.3.2 Saturated Hydraulic Conductivity (Unsaturated Zone).** The soil saturated hydraulic conductivity was either obtained from the NRC site documentation or estimated from soil texture using GIS-based methodologies (Table 6-4). In general, the Subtitle C sites had significantly lower soil hydraulic conductivities (Figure 6-5). This could reflect EPA siting preferences for low-permeability soils. However, although the soils data are site-specific, there is uncertainty in these and other soil properties for sites with deep unsaturated zones because the STATSGO data (STATSGO, 1998) from which they are derived are generally for the top 2.5 meters of soil. They also represent predominant soil properties within a 1-km radius around each site and thus may not precisely represent the soils directly under the landfills in question.

#### **6.3.4 Aquifer Parameters**

Aquifer parameters are presented in Table 6-5. The NRC landfill data were derived from site-specific data (U.S. EPA, 1998; TLLRWDA, 1995; EU, 1991; USE, 1990), while the Subtitle C landfill data are the median values by EPACMTP groundwater class (U.S. EPA, 1996). Groundwater classes were assigned to the Subtitle C sites using HWIR class assignments for nearby Industrial D sites from U.S. EPA (1996). A GIS-based tool, mapping the Industrial D and Subtitle C sites along with physiographic provinces and hydrogeologic regions, was used to make these assignments.

In general, the NRC and EPA aquifer parameters are comparable. For example, aquifer thickness (Figure 6-6) and Darcy velocity values (Figure 6-7) compare well between the different regulated facilities. As with receptor well distance and depth of the vadose zone, no site-specific data were readily available for the Subtitle C facilities. Use of the Industrial D data for these sites adds to the uncertainty of this analysis.

## **7.0 A Comparison of NRC and EPA Requirements**

### **7.1 A Comparison of NRC and EPA Siting Requirements**

#### **7.1.1 Introduction**

Public and private entities planning to construct and operate land disposal facilities for LLW or hazardous waste encounter numerous site selection and approval issues. AEA and RCRA each address site selection through requirements ranging from consideration of sensitive environments (e.g., floodplains) to human health effects of land disposal activities. Land disposal operations have potentially far-reaching and challenging-to-characterize impacts. In addition, landfill performance may be operationally sensitive and require minimal interference from neighboring land use.

This section identifies, evaluates, and compares siting-related regulations in the NRC and EPA programs. Resources used include 10 CFR Part 61 and 40 CFR Parts 264 and 270, sample NRC licensing documents (where available), and senior staff knowledge and experience with the two programs.

This section closes with a model system comprised of the optimum criteria/conditions identified in the siting comparison.

It should be noted that a strict comparison of the EPA and NRC regulations alone may not portray the full set of protections offered by both regulatory approaches. When a permit is issued by EPA or a license is issued by the NRC, it is not unusual that additional protective conditions are added beyond the regulations (e.g., NRC requiring in license that radionuclides be stabilized if their half-lives exceed 5 years). In addition to license conditions, the NRC has issued guidance documents on a variety of subjects (e.g., waste form, performance assessment methodology, etc.) that supplement the applicable regulations by offering acceptable practices or methods for assuring compliance. While it is true that a license applicant does not have to follow such guidance, to depart from it may require considerable time and resources to justify an alternative, thus creating a strong incentive to follow NRC guidance. Similar circumstances hold true for EPA, which has also published technical guidance documents in addition to RCRA permitting requirements.

### 7.1.2 Comparison of NRC and EPA Systems for Protection of Surrounding Land Use: Benefits and Areas of Uncertainty

This section compares NRC and EPA systems for several subject areas potentially falling within the scope of siting, in particular, the protection of surrounding land use:

- # Protection of disposal unit from groundwater intrusion and protection of surface water via groundwater discharge
- # Adverse impact by nearby facilities
- # Development of disposal site selection criteria
- # Capability of site to be characterized, analyzed, modeled, and monitored.

Each subject area compares the benefits and areas of uncertainty of the relevant NRC and EPA systems.

#### 7.1.2.1 Protection of Disposal Unit from Groundwater.

<b>Siting Criteria/Consideration:</b> <b>Protection of Disposal Unit from Groundwater Intrusion and Protection of Surface Water via Groundwater Discharge</b>	
<b>EPA</b>  <b>Benefits</b>  1. Implicit in EPA-compliant designs of landfills is the goal of keeping disposed waste dry, be it by impermeable covers or runoff/runoff control systems.  2. EPA permitting for landfills contains a comprehensive analysis of underlying groundwater characteristics, including direction of flow, flow rate, and other hydrogeologic zones. This analysis should reveal any interaction with surface waters on or near the disposal site.  3. Although the regulations do not explicitly address prevention of groundwater intrusion, the required installation of a bottom liner system to prevent leachate releases to underlying groundwaters can also prevent intrusion.  <b>Areas of uncertainty</b>  None identified	<b>NRC (10 CFR 61. 50(a)(7-8))</b>  <b>Benefits</b>  1. NRC requires that disposal sites provide sufficient depth to groundwater so that the water table will not rise (perennial or otherwise) into the waste disposal unit.  2. NRC requires that hydrogeologic units used for disposal shall not discharge groundwater within the disposal unit.  <b>Areas of uncertainty</b>  1. NRC regulations do not explicitly consider the impact of offsite groundwater to surface water interactions, including use of groundwater for irrigation and runoff from irrigation fields to waterbodies, where applicable. (However, the following case study shows site-specific considerations.)

## **Groundwater Interaction with Surface Water: A Review of One LLW Site to Assess the Role of Offsite Analysis in Decisionmaking**

One LLW site document was reviewed to determine the level of study performed on area hydrology and the potential impact of groundwater interaction with surface water offsite.

*Texas Low-level Radioactive Waste (LLRW) Disposal Authority's Low-level Waste (LLW) Disposal License Application to the State of Texas, for Eagle Flat, January 1994.*

Among the study objectives listed in the Texas document was to answer the following:

*Where are the discharge points (natural and wells) of these aquifers and what is their distance from the site? In the case of an accidental spill, is the distance large enough to allow complete radioactive decay before water reaches the "biosphere?"*

The document refers to groundwater flow offsite and presents the potentiometric surface of aquifers underlying the site. The document also states that the groundwater discharges as natural springs. It acknowledges the presence of karst terrain, which may be a sudden access route for groundwater to the surface. The document states that these karst caverns extend to the surface. However, the study did not look at the actual path and velocities of groundwater through the cavern system.

The document concluded that "Discharge is either by evaporation on the salt flats or through pumping wells." The authors tried to address groundwater surfacing but said a release, after a 100-year institutional control period, would take 45,000 years even to reach the groundwater table (University of Texas, 1994).

In the Texas document, there is an effort to identify surrounding offsite waterbodies and their pathways in relation to the site. The report also characterizes underlying aquifers, their recharge zones, and the discharge areas whether onsite or offsite. However, the author did not directly address whether contaminated groundwater interacts with offsite surface waters and, if so, did not predict the impacts. (This may have been due to the arid climate resulting in low occurrence of surface waterbodies and the depth and extended travel time of aquifers.)

This document indicates that NRC licensing goes beyond the bounds of onsite groundwater/surface water interaction and assesses the proximity of offsite surface waters.

**7.1.2.2 Adverse Impact by Nearby Facilities.** Land disposal operations potentially have far-reaching and challenging-to-characterize impacts (e.g., contaminated groundwater transport). In addition, landfill performance may be operationally sensitive and require minimal interference from activities such as other emission sources on operations that consume similar natural resources (e.g., groundwater). The NRC system contains disposal site suitability requirements, which include “The disposal site must not be located where nearby facilities or activities could adversely impact the ability of the site to meet the performance objectives of subpart C of [10 CFR Part 61] or significantly mask the environmental monitoring program (10 CFR 61.50).”

*Siting Criteria/Consideration:*

**Adverse Impact by Nearby Facilities**

**EPA**

***Benefits***

1. RCRA facility siting must demonstrate that the property can support hazardous waste operations in compliance with EPA design, construction, operation, closure, and postclosure regulations.

***Areas of uncertainty***

1. EPA does not explicitly consider siting of disposal facilities with respect to other facilities (e.g., industry) that could adversely impact the disposal facility's ability to meet environmental monitoring performance objectives. However, this consideration may arise during the development of permit conditions via exercises such as risk assessments.

**NRC (10 CFR 61.50(a)(11))**

***Benefits***

1. NRC regulations require consideration of the impact on disposal operations from nearby activities

2. NRC also considers the potential of a nearby activity's environmental releases significantly masking the NRC-licensed facility's environmental monitoring program.

3. Nearby activities could change groundwater gradient and flow direction.

Therefore, NRC's prevention of confounding issues by neighboring facilities allows characterization of an NRC source-related release or problem.

***Areas of uncertainty***

None identified

**7.1.2.3 Development of Disposal Site Selection Criteria.** Site selection requires consideration of a variety of factors. The formal exercise of developing site selection criteria before beginning a site search provides a comprehensive “checklist” for evaluating candidate sites consistently.

<i>Siting Criteria/Consideration:</i> <b>Development of Disposal Site Selection Criteria</b>	
<b>EPA</b>  <b><i>Benefits</i></b>  1. EPA site selection criteria are implicit through their consideration of waste management in wetlands, 100-year floodplains, earthquake zones, salt domes, coastal areas, etc.  <b><i>Areas of uncertainty</i></b>  None identified	<b>NRC</b>  <b><i>Benefits</i></b>  1. NRC site selection criteria are explicit with bans on construction in wetlands, etc.  <b><i>Areas of uncertainty</i></b>  1. The NRC system does not cite consideration of site selection criteria. As with EPA, NRC regulations implicitly consider issues in site selection through their restrictions on land disposal in wetlands, 100-year floodplains, earthquake zones, high hazard coastal areas, etc.

**7.1.2.4 Capability of Site to be Characterized, Analyzed, Modeled, and Monitored.**

<i>Siting Criteria/Consideration:</i> <b>Capability of Site to Be Characterized, Analyzed, Modeled And Monitored</b>	
<b>EPA (40 CFR 264 Subpart F)</b>  <b><i>Benefits</i></b>  1. Site groundwater monitoring is mandatory.  2. Permit application reviews allow EPA to judge the efficacy of proposed groundwater monitoring plans  <b><i>Areas of uncertainty</i></b>  None identified	<b>NRC (10 CFR 61.50(a)(2))</b>  <b><i>Benefits</i></b>  10 CFR 61.50 (a)(8) requires this consideration  1. This approach results in scrutiny of sites before licensing.  2. This approach results in better preparedness for site analyses and modeling for potential releases.  <b><i>Areas of uncertainty</i></b>  1. The extent to which the NRC assesses this capability in its licensing decision.

### 7.1.3 Comparison of NRC System to EPA System for Protection of Natural Resources: Benefits and Areas of Uncertainty of Systems

The following tables compare NRC and EPA systems for several subject areas potentially falling within the scope of siting, including natural resources:

#	Wetlands
#	100-year floodplains
#	Erosion/slumping
#	Seismic condition
#	Coastal high-hazard areas
#	Protection of groundwater
#	Proximity to populations and development
#	Proximity to natural resources
#	The role of liquids in landfills

*NOTE: The following two topics share a common theme in EPA vs. NRC strategies. EPA allows construction within 100-year floodplains and wetlands if the permit applicant can demonstrate, through engineering, that any threat to the waste site or the surrounding environment can be prevented. NRC prohibits such activity. Therefore, two questions are posed about these diverse strategies: (1) What is the level of certainty in the performance of engineering designs? (2) Is there sufficient land available for EPA siting if construction in floodplains and wetlands were banned?*

**7.1.3.1 Wetlands.** Wetlands are areas that are waterlogged for an extended period of time and include a variety of fish and wildlife habitats. Swamps, marshes, bayous, bogs, and arctic tundra are wetlands. Construction of facilities in and near wetlands can destroy ecosystems. In addition, the high amounts of unstable soils and water in wetlands make them poor areas for land-based hazardous waste structures such as landfills. Any hazardous wastes spilled on wetlands can spread faster through groundwater and surface water. One of the most serious consequences of a hazardous waste spill or leak in wetlands can occur in the process of restoring the wetlands. Removing the contaminated sediments can be very costly and may even destroy the wetlands. Because wetlands are typically found at the headwaters of rivers, lakes, and streams, removal of contaminated bottom sediments in wetlands could unintentionally release contaminants downstream to unsuspecting human, fish, and wildlife populations.

Siting Criteria/Consideration: <b>Wetlands</b>	
<b>EPA (40 CFR 264.601(b))</b>  <b>Benefits</b>  1. EPA's protection of wetlands is implicit via permit application consideration of federal laws including the Endangered Species Act, Coastal Zone Management Act, and Fish and Wildlife Coordination Act, all of which contain provisions related directly or indirectly to wetlands.  2. Any Clean Water Act (CWA) Sections 401 and 404 permitting associated with a disposal facility would require mitigation.  <b>Areas of uncertainty</b>  None identified	<b>NRC (10 CFR 61.50(a)(5))</b>  <b>Benefits</b>  1. NRC prohibits any waste disposal in wetlands (10 CFR 61.50).  <b>Areas of uncertainty</b>  None identified

**7.1.3.2 100-Year Floodplains.** A 100-year floodplain is any land area that is subject to a 1 percent or greater chance of flooding in any given year from any source. Floodplains act as natural storage areas, slowing down rushing floodwaters and reducing downstream flooding. Floodplains also help maintain the quality of rivers and streams by filtering eroded soils and nutrients such as nitrogen and phosphorus.

Siting Criteria/Consideration: <b>100-year Floodplains</b>	
<b>EPA (40 CFR 264.18(b))</b>  <b>Benefits</b>  1. EPA addresses waste disposal unit protection in floodplains through design, construction, operation, and maintenance provisions to prevent washout.  <b>Areas of uncertainty</b>  None identified	<b>NRC (10 CFR 61.50(a)(5))</b>  <b>Benefits</b>  1. NRC bans waste disposal in floodplains (10 CFR 61.50(5)).  <b>Areas of uncertainty</b>  None identified

**7.1.3.3 Erosion/Slumping.** This category may be interpreted more broadly to include unstable terrain and karst terrain. Unstable terrain is divided into two kinds of land movement: (1) the movement of rock and soil on steep slopes by gravity (e.g., landslides) and (2) rock and soil sinking, swelling, or heaving. Mass movement of rock and soil onto a facility can destroy buildings, puncture and bury drums, and break apart earthen structures. Poor foundation conditions can disrupt landfill gas and leachate collection and rip landfill liner systems. Karst terrain consists of rock, such as limestone, dolomite, and/or gypsum, that slowly dissolves when water passes through it. The dissolving rock leaves underground voids, tunnels, and caves. Sometimes these underground spaces can grow so large that their ceilings collapse, forming sinkholes. Approximately 5 percent of the United States has active karst, including Missouri, Kentucky, Florida, Indiana, Arkansas, and Puerto Rico.

<i>Siting Criteria/Consideration:</i> <b>Erosion / Slumping</b>	
<b>EPA (40 CFR 264.18(b))</b>  <b><i>Benefits</i></b>  1. EPA consideration of erosion is implicit via floodplain and runoff/runoff control engineering measures in 40 CFR 264, and it is important that facilities conduct site characterization studies in which they map sinkholes, determine groundwater stability through geotechnical analyses of soil and geologic properties and measure the speed and direction of groundwater flow.  <b><i>Areas of uncertainty</i></b>  None identified	<b>NRC (10 CFR 61.50(a)(10))</b>  <b><i>Benefits</i></b>  1. The effects of erosion on facilities is explicitly addressed in 10 CFR 61.50(a)(10), which mandates avoiding such areas where these areas significantly affect disposal performance objectives and may preclude defensible modeling and prediction of long-term impacts.  <b><i>Areas of uncertainty</i></b>  1. NRC does not specify the soil stability conditions (e.g., sinkholes, karst terrain) to examine. In addition, the phrase “performance objectives” may be subject to broad interpretation and, thus, erosion impacts may not be addressed as thoroughly as necessary.

**7.1.3.4 Seismic Conditions.**

<i>Siting Criteria/Consideration:</i> <b>Seismic Conditions</b>	
<b>EPA (40 CFR 264.18(a))</b>  <b><i>Benefits</i></b>  1. EPA specifies that a facility cannot be located within 200 feet of a Holocene-epoch fault in 40 CFR 264.18(a).  2. In addition, permit application requirements include demonstration that there are no lineations that suggest the presence of a Holocene fault within 3,000 feet of a facility. If within the 3,000-foot area, then the 200-foot rule applies per 40 CFR 270.14(b)(11)(ii)(A).  <b><i>Areas of uncertainty</i></b>  1. Faults beyond 200 feet of a facility or older than Holocene epoch may be capable of impacting a facility.	<b>NRC (10 CFR 61.50(a)(9))</b>  <b><i>Benefits</i></b>  1. NRC prohibits siting of facilities in areas where tectonic activity could impact facility performance objectives in 10 CFR 61.50(a)(9). "Tectonic activity" typically reflects activity within the past 10,000 years, which is essentially the Holocene era.  <b><i>Areas of uncertainty</i></b>  1. NRC does not specify a distance and, therefore, can be interpreted more or less broadly (i.e., a distance greater than 200 feet).

**7.1.3.5 Coastal High-Hazard Areas.**

<i>Siting Criteria/Consideration:</i> <b>Coastal High-Hazard Areas</b>	
<b>EPA (40 CFR 270.3(d))</b>  <b><i>Benefits</i></b>  1. In most cases, compliance entails engineering to prevent flooding (e.g., stormwater ponds). This could be inferred to be inclusive of coastal high-hazard areas.  2. EPA requires the disposal facility to comply with requirements of Coastal Zone Management Act.  <b><i>Areas of uncertainty</i></b>  None identified	<b>NRC (10 CFR 61.50(a)(5))</b>  <b><i>Benefits</i></b>  1. NRC prohibits disposal in a coastal high-hazard area.  <b><i>Areas of uncertainty</i></b>  None identified

### 7.1.3.6 Protection of Groundwater.

#### *Siting Criteria/Consideration:*

### **Protection of Groundwater**

#### **EPA (40 CFR 264.92)**

##### ***Benefits***

EPA regulations explicitly address protection of groundwater in aquifers directly beneath a disposal unit (264.92 through 264.94). If a facility plans to locate over high-value groundwater or where the underground conditions are complex, EPA requires several studies as part of the groundwater investigation such as (a) determining the hydrogeologic complexity and importance of the groundwater for drinking supplies, (b) determining the direction of groundwater flow, (c) assessing the ability of the groundwater to be replenished, and (d) determining how surface waters (e.g., rivers and wetlands) are connected to the groundwater.

##### ***Areas of uncertainty***

None identified

#### **NRC**

##### ***Benefits***

1. An NRC “disposal site” is defined as a subset of the total property. It is comprised of a “disposal unit” (e.g., trench in which waste is placed) and a buffer zone. The buffer zone entails area both under the unit and between the unit and disposal site boundary (10 CFR 61.2) The buffer zone must be adequate dimensions to carry out environmental monitoring activities and take mitigative measures if needed. Given these definitions, monitoring activities required on the “disposal site” implies the intent to detect groundwater contamination early enough to allow mitigation before the contaminant enters the other portions of the owner’s property outside the “disposal site.”

2. The technical information required for licensing a landfill includes -

- # description of the design features related to
  - disposal site monitoring and
  - adequacy of the size of the buffer zone for monitoring and potential mitigative measures (10 CFR 61.12(b))
- # description of the environmental monitoring program to evaluate both health and environmental impacts (10 CFR 61.12(l),
- # the plan for corrective measures if migration occurs (10 CFR 61.12(l)), and
- # groundwater pathway analysis to demonstrate general population protection from radioactive releases (must demonstrate that radioactive release exposure will not exceed NRC limits in 10 CFR 61.41)
- # preoperational environmental monitoring to establish baseline site characteristics (10 CFR 61.55(a))
- # monitoring during construction and operation (10 CFR 61.55 (c))

##### ***Areas of Uncertainty***

1. Monitoring focuses on radionuclides although some language is general and could be interpreted to be broader than radionuclide monitoring. However, the performance goal is protection from exposure to radionuclides above NRC regulatory levels.

2. Via alternative requirements for design and operations (10 CFR 61.54), the NRC always has the authority for site-specific monitoring beyond the regulations. The extent to which the NRC uses this authority is uncertain.

*NOTE: U.S. land disposal sites can be found in quite diverse settings. The following two topics address the impacts of offsite activities on landfill performance.*

1. **Population growth and development** - Urban locations may have once been remote; however, small parcels of land with little buffer and urban sprawl have led to residential populations and commercial development encroaching on disposal sites. NRC focuses on projecting the potential for growth to surround the site and the impact of development on landfill performance
2. **Proximity to natural resources** - The concern exists that exploitation of nearby natural resources (e.g., mining, dam construction/flood control) may alter the land disposal facility's environmental setting and, in turn, its performance in minimizing environmental impacts.

#### **7.1.3.7 Proximity to Populations and Development.**

Siting Criteria/Consideration: <b>Proximity to Populations and Development</b>	
<b>EPA</b>  <b>Benefits</b>  1. EPA assesses proximity via exposure assessments on surrounding populations. After August 1985, any EPA part B application for a landfill must be accompanied by information ascertaining the potential for the public to be exposed to hazardous waste or constituents through releases related to the unit (40 CFR 270.10(j)).  2. EPA does not explicitly assess the impact of projected surrounding populations and development <u>on</u> the facility itself. However, groundwater quality assessments and monitoring plans would identify influences from surrounding land use.  <b>Areas of uncertainty</b>  None identified	<b>NRC (10 CFR 61.50(a)(3))</b>  <b>Benefits</b>  1. NRC requires that a disposal site should be selected so that projected population growth and future development are not likely to affect the ability of the disposal facility to meet its performance objectives (10 CFR 61.50(a)(3)).  <b>Areas of uncertainty</b>  1. This rule can be interpreted via the term "performance objectives" in two ways: (a) the potential for health and ecological impacts, or (b) the reduction in performance of the facility due to interference with groundwater capacity, surface water capacity, watershed, airshed, and property buffer that the facility needs. The latter interpretation appears to be the focus of the NRC, perhaps diminishing the evaluation of health effects.  2. NRC performance objectives are site-specific and may be subject to broad interpretation.

**7.1.3.8 Proximity to Natural Resources.***Siting Criteria/Consideration:***Proximity to Natural Resources**

Both EPA and NRC applicants address siting of facilities proximate to natural resources. However, EPA focuses on environmental impact **to** natural resources. NRC in 10 CFR 61.50(a) considers potential impacts on the facility **from** natural resource activities, e.g., mining, dam construction. Mining could impact groundwater potentiometric surface. Damming waters could re-route natural runoff.

**7.1.3.9 The Role of Liquids in Landfills.***Siting Criteria/Consideration:***The Role of Liquids in Landfills****EPA****Benefits**

1. EPA prohibits disposal of --
  - # bulk or non-containerized liquids in landfills
  - # waste containing free liquids
  - # Liquids which are not hazardous wastes. (40 CFR 264.314)
2. Containers holding free liquids are prohibited unless the liquid is decanted or mixed with sorbent or solidified so that free-standing liquid is no longer observed. (40 CFR 264.314)
3. EPA requires co-disposal of only chemically compatible wastes. (40 CFR 264.313)
4. Wastes must be compatible with their containers and the materials of construction of the disposal unit. (40 CFR 264.313)
5. Landfills must be designed, constructed and operated with run-on diversion controls. (264.301(g))
6. Cover impermeabilities must be at least as great as bottom liners (so that they prevent infiltration). (40 CFR 264.310(a)(5))

Presuming the acceptable performance of covers to prevent percolation/infiltration of rainfall (40 CFR 264.310), these requirements eliminate the potential for reactions that could promote liquid generation or releases from waste containments, be they drums or engineered liner systems.

**Areas of uncertainty**

None identified

**NRC****Benefits**

1. NRC prohibits disposal of liquids in LLRW disposal facilities, i.e.,
  - # Solidify liquid waste, or
  - # Package with absorbent material to absorb twice the liquid volume, assuring as little freestanding and noncorrosive liquid achievable but neve to exceed 1% of volume.
2. Waste must be disposed of in waste compatible containers (10 CFR 61.52(a)(4))
3. NRC closure specifications directs minimization, to the extent practicable,
  - # water percolation/infiltration,
  - # waste contact with standing water during disposal,
  - # waste contact with standing or percolating water after disposal (10 CFR 61.51(a)(6)).
4. Landfill closure specifications include
  - # direct percolating or surface water away from disposed waste
  - # resist degradation by surface geologic processes and biotic activity (10 CFR 61.51(a)(4)).

**Areas of uncertainty**

1. NRC's direction to "minimize to the extent practicable" provides uncertain ranges of potential for waste contact with infiltrate.
2. Waste-to-waste compatibility is not addressed.

### 7.1.4 Model Siting Criteria/Considerations for Mixed Low-level Radioactive Waste

This section presents a model siting system that compiles the most protective measures identified in the previous comparisons.

#### Model Siting Criteria/Consideration for Mixed Low-level Radioactive Waste

1. Consider the adverse impact of nearby facilities.
2. Develop disposal site selection criteria.
3. Protect disposal unit from groundwater intrusion.
4. Protect onsite and nearby offsite surface waters from contaminated groundwater discharges.
5. Protect groundwater from contamination.
6. Prohibit land disposal in wetlands.
7. Prohibit land disposal in 110-year floodplains.
8. Avoid areas where erosion/slumping can significantly affect disposal performance objectives.
9. Prohibit land disposal in areas where tectonic activity could impact facility performance.
10. Prohibit land disposal in high hazard coastal areas.
11. Select disposal site so that projected population growth and future development are not likely to affect the ability of the disposal facility to meet its performance objectives.
12. Consider the sensitivity and influence of natural resources.
13. Consider the capability of the site to be characterized, analyzed, modeled, and monitored.
14. Prohibit disposal of liquids.

## 7.2 Comparison of EPA-Regulated RCRA Post-closure Care Regulations to NRC-Regulated Institutional Controls: Benefits and Areas of Uncertainty

### 7.2.1 Introduction

The NRC uses the term “Institutional Control” to refer to the period that follows land disposal site closure and during which periodic maintenance and monitoring activities are conducted. The facility is assumed to be closed, stabilized, and maintained but is still part of the parent facility.

The comparable RCRA activity is referred to as the postclosure period during which monitoring and maintenance occur 30 years after the land disposal unit’s closure.

### 7.2.2 Comparison of NRC to EPA Requirements

The following tables compare several subject areas potentially falling within the scope of institutional control:

- # Ownership
- # Buffers
- # Postclosure care
- # Public records of closed site.

Each topic compares the benefits and areas of uncertainty of the relevant NRC and EPA-regulated systems.

This section closes with a model system comprised of the optimum conditions identified during the comparison.

#### 7.2.2.1 Ownership.

<b><i>Institutional Control:</i></b> <b>Ownership</b>	
<b>EPA (40 CFR 264 Subpart H and 270.40)</b>  <b><i>Benefits</i></b>  1. Financial assurance mechanisms strengthen ownership liability and, in turn, quality of management/protection.  2. No regulations prevent transfer of ownership during the active or postclosure life of the facility. However, financial assurance demonstrations by all owners (or prospective owners) must be made in order to receive a permit. This demonstrates the owner's ability to financially manage a range of operating scenarios, the new owner must submit a Class I permit modification to demonstrate the new owner's technical ability to operate the facility in compliance.  <b><i>Areas of uncertainty</i></b>  None identified	<b>NRC (10 CFR 61.14)</b>  <b><i>Benefits</i></b>  Unlike RCRA, commercial NRC-licensed facilities are owned by federal or state governments and leased to commercial operators. Government ownership reduces uncertainty about liability and the reliability of the owner's financial assurance for compliant operation and closure of facilities.  <b><i>Areas of uncertainty</i></b>  1. The license and, in turn, responsibility for the disposal site, may be transferred to another party 5 years after completion of closure. A change in ownership/license always runs the risk of loss of institutional memory, i.e., an historic perspective on the nuances of the site's design, operation, and performance.

**7.2.2.2 Buffers.**

<b><i>Institutional Control: Buffers</i></b>	
<p><b>EPA (40 CFR 264.176 and 264.31)</b></p> <p><b><i>Benefits</i></b></p> <ol style="list-style-type: none"> <li>1. EPA specifies a 50-ft buffer specific for storage of ignitables and reactives (264.176).</li> <li>2. Although EPA regulations do not explicitly address the determination of a suitable distance for other waste management operations, permit application reviews on groundwater monitoring plans, runoff and runoff control plans, and risk assessments may lead to permit conditions addressing buffer distances.</li> </ol> <p><b><i>Areas of uncertainty</i></b></p> <p>None identified</p>	<p><b>NRC (10 CFR 61.12 and 61.52)</b></p> <p><b><i>Benefits</i></b></p> <ol style="list-style-type: none"> <li>1. NRC states that the site-specific buffer distance be adequate to allow environmental monitoring and mitigative measures for releases.</li> </ol> <p><b><i>Areas of uncertainty</i></b></p> <ol style="list-style-type: none"> <li>1. NRC does not provide a detailed definition of environmental monitoring and mitigative measures; therefore, the criteria for buffer distance is not well-defined.</li> <li>2. NRC does not explicitly address buffer distances for the purpose of protecting human health and the environment. Rather, it indirectly addresses this function through requirements for adequate distance to mitigate.</li> </ol>

**7.2.2.3 Postclosure Care Period.*****Institutional Control:*****Post-closure Care Period****EPA (40 CFR 264.1 17(a)(1))*****Benefits***

Post-closure environmental monitoring is more explicitly defined for EPA landfills than NRC landfills. The same environmental monitoring program (e.g., groundwater monitoring wells) that operates during the landfill's active life must be continued during the 30-year postclosure period. NRC rules do not state the extent of "environmental monitoring" required. EPA's more explicit requirements promote a more proactive approach to ensuring landfill integrity and, in turn, protection of human health and the environment.

2. EPA requires the groundwater analysis of a select list of RCRA hazardous chemical contaminants.
3. Post-closure care (e.g., maintenance, monitoring) can be extended beyond 30 years if the EPA Regional Administrator (RA) specifies an extension for the site.
4. Although the 30-year care period is one-third of the NRC post-closure control period (100 years), landfills with synthetic covers may last longer, thus reducing leachate generation.
5. The RA can choose to require continuation of any or all of the security requirements during part or all of the post-closure care period if (1) the waste remains exposed after closure, or (2) access by the public or domestic livestock may pose a risk to human health.
6. The RA must deem that after 30 years the activity onsite will not increase the potential hazards.

***Areas of uncertainty***

1. No restrictions exist on the length of post-closure ownership by the permit holder. (NRC requires 5 years.) A change in ownership during the post-closure period leaves uncertainty about the retention of institutional memory and, in turn, quality of care and response to incidents (e.g., releases detected in groundwater monitoring systems).

**NRC (10 CFR 61.59(b))*****Benefits***

1. The landowner or custodial agent of an NRC-licensed disposal facility must carry out a 100-year institutional control program following transfer of control of the site from the disposal site operator.
2. NRC regulations not only require maintenance and monitoring of landfills during post-closure (as with EPA), these also require observing, which may be interpreted as periodic surveillance not only for physical changes in the site's appearance, but also visually monitoring for intruders.

***Areas of uncertainty***

1. NRC does not require groundwater monitoring for specific hazardous chemical contaminants.
2. The license and, in turn, responsibility for the disposal site, may be transferred to another party 5 years after completion of closure. A change in ownership/license always runs the risk of loss of institutional memory, i.e., an historic perspective on the nuances of the site's design, operation, and performance.
3. The NRC has the authority to shorten (or lengthen) the 5-year postclosure period on a site-specific basis.

**7.2.2.4 Public Records of Closed Sites.**

<b><i>Institutional Control:</i></b> <b>Public Records of Closed Sites</b>	
<b>EPA (40 CFR 264.119)</b>  <b><i>Benefits</i></b>  1. EPA requires owner/operators to provide more detail about the contents of closed sites than NRC, specifically, the type of waste disposed and the specific landfill unit, in addition to the location and quantity that both the NRC and EPA systems require.  2. EPA requires a notation on the facility property deed that the land was used to manage hazardous waste, its restricted use under 264 Subpart G, and a survey plat. NRC does not explicitly require these.  <b><i>Areas of uncertainty</i></b>  None identified	<b>NRC (10 CFR 61.80)</b>  <b><i>Benefits</i></b>  1. Upon license termination, NRC regulations require the notification of the following parties:  # Chief executive of nearest municipality # Chief executive of host county # Host county's zoning board on land development and planning # Host state's governor # Other state, local, and federal government agencies noted by NRC upon termination of license.  This notification list is beneficial in that it precludes any communication gaps for activities such as industry recruiting by state commerce departments, utilities distribution system planning, etc.  <b><i>Areas of uncertainty</i></b>  1. NRC regulations are not explicit as to what records the licensee shall send to government entities upon license termination. This may result in information gaps such as monitoring well or disposal cell surveyed locations leading to inadvertent disturbance of the area and its ancillary operations if adjacent property is developed, farmed, or timbered.  2. NRC does not require that information on the waste type and its disposal unit location be provided to government entities.  3. NRC does not require notations on property deeds of land disposal locations, restricted use, or survey plats.

### 7.2.3 Model Institutional Controls for Mixed Low-Level Radioactive Waste

#### **Model Institutional Controls For Mixed Low-level Radioactive Waste**

1. More explicit post-closure environmental monitoring
2. 100-year institutional controls after closure
3. Restrictions on the length of post-closure ownership by the permit/license holder
4. Observance of the site post-closure (e.g., periodic surveillance for physical changes in site's appearance and visual monitoring for intruders)
5. Notify a broader number of parties upon facility closure
6. In addition to notifying parties of the location and quantity of waste disposed, also inform them of the waste type
7. Explicitly require notation on the facility property deed that the land was used to manage hazardous waste, its restricted use, and a survey plat
8. Explicitly require set frequencies of disposal site inspections
9. Designate buffer distances from edge of disposal unit to property boundary

## 8.0 Risk Characterization

This section identifies the primary sources of uncertainty associated with the comparative and technical analyses in this document and qualitatively describes how each may influence the results of these analyses. Sources of uncertainty identified in the analyses include the following:

- # Outside sources of data. Because of the comparative nature of the technical approach, most of the data in this document were derived from outside sources. Even though quality assurance protocols were used, it was impossible to remove all uncertainty from data generated by other parties. Some of the most important and sensitive parameters this document's analyses include are those that describe waste composition, waste management practices, and site characteristics (e.g., hydrogeological, topographical, meteorological, and soils data). While not specifically addressed in the technical approach, the parameters and exposures considered include the physical, chemical, and biochemical properties of the hazardous waste contaminants, and toxicological effects that were indirectly factored in using specific benchmarks (e.g., MCL and UTS).
- # Groundwater data on chemical constituents at LLRW disposal facilities. Groundwater monitoring data for chemical constituents from wells surrounding LLRW disposal facilities were not available to help assess whether chemical constituent releases have occurred at these facilities. Although groundwater monitoring information was available on radioactive constituents, the lack of chemical data results in the inability to evaluate the relationship of radionuclides to chemicals for fate and transport and the potential risk to receptors for all possible waste constituent combinations. For example, chemical constituents present in mixed waste could be either more or less mobile than the radioactive constituents present in mixed waste, resulting in either an over- or underestimation of chemical hazards.
- # Screening-level analysis of LDR treatment relative to groundwater protection. The analysis conducted to evaluate LDR treatment in the context of groundwater protection was of a screening nature and not all-inclusive. The information used was limited to chemical constituents where values exist for MCLs, LDR treatment standards (i.e., UTSSs), and DAFs. The gaps in these data that result from lack of MCL, UTS, or DAF values may result in either an overestimation or underestimation of the potential chemical hazard to receptors. In addition, the use of UTS connotes that all waste managers only meet the standard, while most will treat to levels lower than the UTS. The DAF values used in this analysis were based on a previous EPA national analysis and for an infinite source of waste in

the disposal unit. The use of nationally available UTS and DAF values tends to overestimate the chemical hazard.

- # Lack of quantitative risk analysis. This document does not contain a quantitative, risk-based analysis of potential disposal sites, and it does not quantitatively estimate the risk of developing cancer from the potential exposure to chemical contaminants in waste. The lack of a quantitative risk analysis leads to sources of uncertainty in assessing the most sensitive potential toxicological effects, exposure routes, and constituents of concern within the waste. Although the analysis did factor in site-specific data, it did not address future siting of LLRW disposal facilities because of the difficulty of siting new facilities such as the recent rejections of the Ward Valley, CA, site and the Nebraska site. As a result, this document's technical analyses might also result in either potential overestimates or underestimates of the potential chemical hazard to receptors.
- # Sensitive subpopulations and environments. Due to EPA's decision not to conduct risk modeling, the technical analysis did not specifically assess risks to sensitive subpopulations and environments. The likelihood that landfills are located in environmental areas where constituents might move significantly with groundwater is uncertain. In addition, the following factors might significantly increase or decrease the mobility of chemical constituents in groundwater in the short term (e.g., seasonal variation) as well as long term (e.g., 10,000 years): waste treatment; waste packaging; waste form requirements; the existence of physicochemical limitations (e.g., interactions between contaminants and aquifer material); biological and chemical degradability of other constituents that may be present (e.g., sandy or other porous soils); soil organic matter and clay content; soil exchange capacity; dissolved organics or organic acids in the groundwater; competing cations; changes in soil environmental conditions such as organic waste matrix, pH, redox potential, or soil solution composition over time; and other physical and chemical characteristics of the groundwater and geological medium.
- # Groundwater protection attained through NRC licensing. The likelihood that the NRC licensing process will apply more stringent groundwater protection requirements and criteria to mitigate radiological releases to the groundwater is given; however, it is uncertain whether NRC groundwater protection requirements could mitigate chemical releases to the groundwater. It is known that if releases do occur, the regulatory agency is likely to require cleanup of all contamination, not just radionuclides.
- # State requirements. The extent to which state requirements will address some of the key landfill design factors and groundwater monitoring, as discussed above, is uncertain.

# \_\_\_\_\_ The technical analyses presented in this document were not subjected to external peer review prior to rule proposal, but EPA plans to conduct

In closing, potentially significant uncertainties exist about whether (and how) exposure to mixed waste constituents will occur. Also, the comparison between NRC and EPA land disposal

EPA lead to a certain degree of uncertainty in making the comparative analyses used in this study. In addition, the variations in site-specific conditions and the implementation of

protection of human health and the environment. The comparison was intended to approximate real-world conditions and processes and their relationships. However, because of the nature of

activity” mixed waste proposal did not include all parameters or equations commonly seen in a detailed risk-based modeling approach. Consequently, the technical approach was based on

or underestimation of the potential comparative protectiveness between the EPA hazardous waste and the NRC LLRW disposal systems.

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## Appendix A: Regulatory Comparison

This appendix contains the results of research and tabulation of a comparison between Resource Conservation and Recovery Act (RCRA) and Nuclear Regulatory Commission (NRC) technical requirements related to waste management. The attached matrices include regulatory citations and assigned values/methods, where applicable. A matrix is provided for each of the following topics.

Table A-1.	Waste classification
Table A-2.	Waste treatment
Table A-3.	Disposal cell engineering design criteria
Table A-4.	Active unit operations management
Table A-5.	Corrective (remedial) action
Table A-6.	Closure
Table A-7.	Site properties
Table A-8.	Performance.

Each table is preceded by a short narrative of the comparison.

To develop these tables, Internet sites for EPA and NRC were researched to identify the most current regulations and policy directives applicable. The primary resources used to develop the tables were

- # EPA - 40 CFR 260 through 270
- # NRC - 10 CFR 61 - Licensing Requirements for Land Disposal of Radioactive Waste and 10 CFR 20 - Standards for Protection Against Radiation.

Empty boxes under the “Authorities” headings indicate that no **specific** regulatory language was found (although the topic may be inherent to the authority’s program).

**TABLE A-1. WASTE CLASSIFICATION**

The review of regulations proved difficult to find commonalities between EPA and NRC regulations on waste classification to allow a comparative analysis. EPA regulations focus on chemical constituents, and NRC regulations focus on radionuclides. NRC refers to mixed wastes (along with EPA compliance) and also, in some cases, requires the determination of physical and chemical characteristics of wastes. However, the ultimate performance goals and regulations of NRC regulations focus on the prevention of release and exposure to radionuclides.

NRC regulations classify wastes as A through C. Each class is a function of the radionuclide's concentration expressed as curies. EPA regulations are chemically driven characterizations. They possess one or more of four characteristics (ignitable, corrosive, reactive, or toxic). In addition to general characteristic wastes, additional wastes are listed based on the presence of hazardous constituents and the source of the waste (e.g., a specific industrial process).

Near-surface disposal (versus deep disposal such as salt mines) of radioactive waste distinguishes between Class A and C wastes in that Class A wastes must be segregated from Class C wastes unless A is suitably stabilized. RCRA land disposal regulations set aside special conditions for the disposal of ignitable, reactive, incompatible, and dioxin- or furan-containing wastes (e.g., F023). In addition, wastes are restricted from land disposal based on the treatability of their hazardous constituents.

**Table A-1. Waste Classification**

Topic	Authority	
	EPA	NRC
<b>Categories</b>	<p>Characteristic</p> <p>Ignitable</p> <p>Corrosive</p> <p>Reactive</p> <p>Toxic</p> <p>Hazardous wastes from non-specific sources</p> <p>Hazardous wastes from specific sources</p> <p>Discarded commercial chemical products, off-spec species, container residuals, and spill residues thereof (Listings and appendices do not contain any radionuclides) <i>40 CFR 261</i></p>	<p>Classes A, B, and C (a function of the radionuclide(s)' concentration expressed as curies)</p> <p>See attached explanation of each class <i>10 CFR 61.55(a)</i></p>
<b>Characterization</b>	<p>Waste characterization procedures* for</p> <ul style="list-style-type: none"> <li>Generators <i>40 CFR 262.11</i></li> <li>TSD owner/operators <i>40 CFR 264.13 and 268.7</i></li> </ul> <p>*Waste analysis (chemical and physical) and/or knowledge of waste</p>	<p>(See "Active Unit Operations Management" matrix)</p>

**TABLE A-2. WASTE TREATMENT**

Only EPA regulations contain regulations on treatment of waste before disposal. The only unit-specific treatment standards found in NRC regulations are for incineration of radioactively-contaminated waste oils, scintillation fluid vials, animal tissue, and specially approved wastes. Waste oil incineration emission levels are specified for each facility license. NRC incineration regulations for animal waste and vials are based on the level of radioactivity whereas EPA incineration regulations are performance-based (destruction and removal efficiency) and have certain emission limits. Unlike EPA regulations, NRC incineration regulations do not contain specific operating regulations.

RCRA 40 CFR 264 also contains regulations for treating wastes in containers, tanks, surface impoundments, wastepiles, containment buildings, and miscellaneous units. However, mixed wastes are excluded from EPA regulations which control volatile organic air emissions from containers, tanks, and impoundments.

**Table A-2. Waste Treatment**

Topic	Authority	
	EPA	NRC
<b>Land Disposal Restrictions</b>	<p>Before land disposal mixed wastes must, comply with treatment standard (both specific and nonspecific mixed waste; if nonspecific, refer to EPA waste code for respective hazardous waste) <i>40 CFR 268.40 and 268.48</i></p> <p>Hazardous debris containing radioactive waste <i>40 CFR 268.45</i></p> <p>Universal treatment standards used to regulate most hazardous wastes prohibited from land disposal <i>40 CFR 268.48</i></p>	
<b>Containers, Tanks, Surface Impoundments, Wastepiles, Containment Buildings</b>	<p>Unit-specific design and operating standards for treatment in:</p> <ul style="list-style-type: none"> <li>• Containers <i>40 CFR 264, Subparts I, AA, BB, and CC*</i></li> <li>• Tanks <i>40 CFR 264, Subparts J, AA, BB, and CC*</i></li> </ul>	
<b>Containers, Tanks, Surface Impoundments, Wastepiles, Containment Buildings (continued)</b>	<ul style="list-style-type: none"> <li>• Surface impoundments <i>40 CFR 264, Subpart K, AA, BB, and CC*</i></li> <li>• Wastepiles <i>40 CFR 264, Subpart L</i></li> <li>• Containment Buildings <i>40 CFR 264, Subpart DD</i></li> <li>• Excludes units used solely for the management of radioactive mixed waste <i>40 CFR 264.1080(a)(6)</i></li> </ul> <p>* Subpart CC excludes mixed wastes.</p>	

(continued)

Table A-2. (continued)

Topic	Authority	
	EPA	NRC
<b>Incineration</b>	<ul style="list-style-type: none"> <li>• Performance standards: <ul style="list-style-type: none"> <li>- DRE of 99.99% for POHCs</li> <li>- DRE of 99.99997% for POHCs more difficult to burn than TCDD, PCDD, HCDD and dibenzofurans</li> <li>- Control HCl emissions</li> <li>- Control particulate emissions</li> </ul> </li> <li>• Permit-specific operating limits for: <ul style="list-style-type: none"> <li>- CO</li> <li>- Waste feed rate</li> <li>- Combustion temperature</li> <li>- Combustion gas velocity</li> </ul> </li> <li>• Start-up/shutdown conditions</li> <li>• Fugitive emissions control</li> <li>• Automatic waste feed cutoff</li> <li>• Cease operation circumstances</li> </ul> <p><i>40 CFR 264 Subpart O</i></p>	<ul style="list-style-type: none"> <li>• Waste oils contaminated during licenses nuclear power reactor operation or maintenance. Oil must be incinerated on the site of generation. Incineration effluents must conform to 10 CFR 50's Appendix I. Effluent release limits for incinerator must be specified in license. Solid residues from such incineration must be disposed per 10 CFR 20.200</li> <li>• Allowed to incinerate scintillation fluids <math>\leq 0.05 \mu\text{Ci}</math> of <math>\text{H}^3</math> or <math>\text{C}^{14}</math> per gram per 10 CFR 20.2005</li> <li>• Allowed to incinerate animal waste tissue <math>\leq 0.05 \mu\text{Ci/g}</math> of entire body weight per 10 CFR 20.2005</li> <li>• Allowed to incinerate wastes that are specifically approved by the NRC per 10 CFR 20.2002</li> </ul> <p><i>10 CFR 20.2004</i></p>
<b>Performance</b>	<p>See "Incineration" and "Land Disposal Restrictions"</p> <p>Miscellaneous units must be located, designed, constructed, operated, maintained, and closed in a manner that will ensure protection of human health and the environment <i>40 CFR 264.601</i></p> <p>Process vents:</p> <ul style="list-style-type: none"> <li>• Numeric emission reductions at vent or</li> <li>• Control device performance standard <i>40 CFR 264.1032, .1033</i></li> </ul>	

(continued)

Topic	Authority	
	EPA	NRC
	Equipment Leaks:  • Combination of equipment and performance standards <i>40 CFR 264, Subpart BB</i>	
<b>Operation</b>	See “Incineration” and “Containers, Tanks, Surface Impoundments, Wastepiles, Containment Buildings”	

**TABLE A-3. DISPOSAL CELL ENGINEERING DESIGN CRITERIA**

NRC regulations contain specific design criteria. EPA regulations contain design specifications corresponding to the variety of topics found in NRC design criteria.

NRC design criteria focus generally on (1) improving the ability of the disposal site’s natural character to assure attainment of performance objectives, and (2) design features that are directed toward long-term isolation and avoidance on post-closure maintenance.

NRC design criteria contain information about cover performance, erosion control, keeping disposed waste dry, and closure. EPA regulations address these topics through design and operating regulations. NRC regulations particularly share common specifications with EPA regulations on covers and erosion control. EPA regulators, however, also require a cover’s permeability be less than or equal to the bottom liner’s permeability. (NRC regulators do not explicitly require liners.) EPA-mandates erosion control specifies a 25-year, 24-hour storm event; NRC does not specify a storm event.

EPA regulations stand alone when it comes to liner and leachate detection/collection/removal system specifications for wastepiles, surface impoundments, and landfills. NRC does not require liners. EPA regulations also stand alone in that they contain wind dispersal regulations for particulates from wastepiles and landfills.

**Table A-3. Disposal Cell Engineering Design Criteria**

Topic	Authority	
	EPA	NRC
<b>Applicability</b>	New disposal units including Wastepiles, surface impoundments, and landfills <i>40 CFR 264.251, .221, and .301, respectively</i>	Near surface disposal <i>10 CFR 61.51</i>
<b>Based on physiographic data</b>		Complement and improve, where appropriate, the ability of the disposal site's natural characteristics to assure site meets objectives of 10 CFR Subpart C (i.e., $\leq 25$ mrem/yr, etc.) <i>10 CFR 61.51(a)(3)</i>
<b>Based on environmental data</b>		
<b>Based on hydrogeological data</b>		
<b>Based on projected waste volumes</b>		Design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after site closure <i>10 CFR 61.51(a)(i)</i>
<b>Covers</b>	<u>Landfill and Surface impoundments:</u> <ul style="list-style-type: none"> <li>• Longterm minimization of migration of liquids through the closed landfill</li> <li>• Minimum maintenance</li> <li>• Promote drainage and minimize erosion or abrasion of cover</li> <li>• Accommodate settling and subsidence</li> <li>• Permeability <math>\leq</math> permeability of bottom liner system or natural subsoils</li> </ul> <i>40 CFR 264.310</i> (landfills)  <i>40 CFR 264.228</i> (impoundments)	1) Minimize, to the extent practicable, water infiltration  2) Direct percolating or surface water away from the disposed waste  3) Resist degradation by surface geologic processes and biotic activity <i>10 CFR 61.51(a)(4)</i>

(continued)

**Table A-3. (continued)**

Topic	Authority	
	EPA	NRC
<b>Liner [or exemption] system</b>	<p>Surface Impoundment 40 CFR 264.221(a) and (c)(1); [(b)]</p> <p>Wastepile 40 CFR 264.251(a)(1); [(b)]</p> <p>Landfill 40 CFR 264.301(a) and (c)(1); [(b)]</p>	
<b>Erosion control</b>	<p><u>Wastepile:</u></p> <ul style="list-style-type: none"> <li>Run-on control system 40 CFR 264.251(g)</li> <li>Runoff control 40 CFR 264.251(h)</li> </ul> <p><u>Landfill:</u></p> <ul style="list-style-type: none"> <li>Run-on control system 40 CFR 264.301(g)</li> <li>24-hour/25-year storm runoff control 40 CFR 264.301(h)</li> </ul>	<p>Surface features direct surface water drainage away from units at velocities and gradients to avoid erosion that requires ongoing active maintenance in the future 10 CFR 61.5(a)(5)</p>
<b>Wind dispersal control of particulates</b>	<p>Wastepile 264.251(j)</p> <p>Landfill 264.301(j)</p>	
<b>Keeps wastes dry</b>	<p><u>Surface impoundment:</u></p> <p>Leachate collection and removal system and leak detection system 40 CFR 264.221</p> <p><u>Wastepile</u></p> <p>Leachate collection and removal system 40 CFR 264.251(a)(2)</p> <p><u>Landfill</u></p> <p>Leachate collection and removal system and leak detection system 40 CFR 264.301(c)(2), (3)</p>	<p>Minimize, to the extent practicable:</p> <ul style="list-style-type: none"> <li>Contact with water during waste storage</li> <li>Contact with standing water during disposal</li> <li>Contact with standing or percolating water after disposal 10 CFR 61.(a)(6)</li> </ul>
<b>Closure</b>	See Table A-6	<p>Compatible with site closure and stabilization plan 10 CFR 61.51(a)(2)</p>

**TABLE A-4. ACTIVE UNIT OPERATIONS MANAGEMENT**

EPA and AEA regulations are consistent in certain wastes restricted from land disposal. These are liquids and reactive wastes. NRC regulations appear to only address segregation of Class A radioactive wastes from Class C wastes, unless Class A wastes are suitably stabilized.

All three authorities address proper mapping and/or marking of disposal areas and their associated monitoring wells. Buffer zones (distance from waste unit to facility boundary) apply to ignitables for EPA regulations. NRC regulations require a distance from any waste management unit to be adequate to carry out environmental monitoring and mitigative measures.

EPA and NRC regulations each address operating goals but in different manners. EPA regulations address operating goals via practices specified in each permit. NRC regulations focus on closure and stabilization measures along with compliance with dose limits of performance goals.

Both EPA and NRC regulations address runoff management but only EPA regulations contain operating conditions for leachate collection/removal systems and wind dispersal of particulates.

EPA regulations require weekly inspections of landfills. NRC simply requires generic environmental monitoring and does not specify inspection frequencies.

EPA regulations require a sophisticated groundwater monitoring program. NRC regulations require monitoring but do not elaborate generically. Environmental monitoring may include subsurface water to detect changing trends to allow corrective action prior to exceeding performance objectives.

**Table A-4. Active Unit Operations Management**

Topic	Authority	
	EPA	NRC
<b>Disposal: Waste restrictions</b>	<p>No ignitable or reactive waste unless no longer meets definition (Conditions allowed for disposal of ignitables) <i>40 CFR 264.256 (wastepile) and 40 CFR 264.312 (landfill)</i></p> <p>No incompatible wastes in same landfill (unless 264.17(b) complied with) <i>40 CFR 264.257 (wastepile) and 40 CFR 264.313 (landfill)</i></p> <ul style="list-style-type: none"> <li>• No bulk or non-containerized liquid hazardous waste</li> <li>• No hazardous waste containing free liquids</li> <li>• No liquid which is not a hazardous waste (conditions allowed) <i>40 CFR 264.314</i></li> </ul> <p>Containers disposed must be <math>\geq 90\%</math> full (except very small containers) or . . . reduced in volume <i>40 CFR 264.315</i></p>	<p>Dispose only waste containing or contaminated with radioactive materials <i>10 CFR 61.52(a)(11)</i></p> <p>Unless Class A wastes are stabilized (10 CFR 61.56(b)), adequately segregate Class A wastes from other wastes in disposal units <i>10 CFR 61.52(a)(1)</i></p> <p>Dispose Class C wastes either</p> <ul style="list-style-type: none"> <li>• a minimum of 5 m below top surface of cover, or</li> <li>• provide <math>\geq 500</math>-year intruder barriers <i>10 CFR 61.52(a)(2)</i></li> </ul> <p>Emplace waste in unit to maintain package integrity <i>10 CFR 61.52(a)(4)</i></p> <ul style="list-style-type: none"> <li>• Do not package for disposal in cardboard or fiberboard boxes</li> </ul>
	<p>Labpack disposal specifications <i>40 CFR 264.316</i></p> <p>Conditional disposal of F020, F021, F022, F023, F026, and F027 <i>40 CFR 264.259 (wastepile) and 40 CFR 264.317 (landfill)</i></p> <p>Land Disposal Restrictions banning wastes unless they meet treatment standards <i>40 CFR 268</i></p>	<ul style="list-style-type: none"> <li>• Solidify liquid waste or package with absorbent material to absorb twice the liquid volume</li> <li>• As little freestanding and noncorrosive liquid as is achievable but never to exceed 1% of the volume</li> </ul>

(continued)

**Table A-4. (continued)**

Topic	Authority	
	EPA	NRC
<b>Disposal: Waste restrictions (continued)</b>		<ul style="list-style-type: none"> <li>• Not readily capable of detonation or of explosive decomposition or reaction at normal temperature and pressure, or explosive reaction with water</li> <li>• Must not contain or be capable of generating gases harmful to persons handling waste except gases packaged at pressure <math>\leq 1.5</math> atm at 20°C.</li> <li>• Not be pyrophoric <i>10 CFR 61.56</i></li> </ul>
<b>Identification markers for disposal excavations and monitoring wells</b>	Map location, dimensions, and record contents of each landfill cell; permanently surveyed benchmarks <i>40 CFR 264.309</i>	Also mapping of each unit; NGS or U.S. Geologic Survey (USGS) marker specifications <i>10 CFR 61.52(a)(7)</i>
<b>Training</b>	<ul style="list-style-type: none"> <li>• Facility personnel</li> <li>• Hazardous waste management</li> <li>• Emergency procedures</li> <li>• Within 6 months of employment or new position</li> <li>• Annual review</li> <li>• Recordkeeping <i>40 CFR 264.16</i></li> </ul>	
<b>Minimize voids between containers</b>		<i>10 CFR 61.52(a)(4), (5)</i>
<b>Conduct operations in active areas to minimize adverse effects on filled units</b>		<i>10 CFR 61.52(a)(10)</i>
		(continued)

**Table A-4. (continued)**

Topic	Authority	
	EPA	NRC
<b>Operating Goals</b>	Regional Administrator specifies in permit all operating practices necessary to satisfy requirements of section 40 CFR 264.301(K)	Carry out closure and stabilization measures per closure plan 10 CFR 61.52(a)(9)  Waste placed and covered to comply with dose limits established in 10 CFR 61.1301 and .1302 10 CFR 61.52(a)(6)
<b>Buffer zone</b>	Containers holding ignitable or reactive waste must be located at least 15 meters (50 ft) from the facility's property line 40 CFR 264.176	Between waste and disposal boundary; adequate buffer to carry out environmental monitoring and take mitigative measures 10 CFR 61.52(8)
<b>Alternative operation requirements</b>	Facility specific; demonstrate that alternative, in combination with location characteristics, will prevent migration of hazardous constituents into groundwater or surface water at any time. (Information requirements, too) 40 CFR 264.301(b), (d)	Facility specific; assure compliance with performance objectives of Subpart C 10 CFR 61.54
<b>Leachate collection and removal system for landfills</b>	Operate through post-closure 40 CFR 264.301(c)(2)  Remove pumpable liquids in system to minimize head on bottom liner 40 CFR 264.301(c)(4)	
<b>Control wind dispersal</b>	40 CFR 264.301(j)	
<b>Runoff management</b>	24 hour 25 year storm system 40 CFR 264.301(h)	10 CFR 61.51(a)(4), (5) (No storm event specified)
<b>Inspection</b>	Weekly	Generic environmental monitoring regulations. Does not specify inspections 10 CFR 61.53
<b>Groundwater monitoring program</b>	40 CFR 264.91 - .99	Generic. Does not specify media monitored 10 CFR 61.53(c)

**TABLE A-5. CORRECTIVE (REMEDIAL) ACTION**

Both authorities contain provisions for corrective action to mitigate releases of contaminants. NRC regulations are the most general, requiring the license contain a corrective action plan for release of radionuclides, a monitoring program during construction and operation, and a goal to maintain radiation exposure As Low As Reasonably Achievable (ALARA).

The EPA's corrective action plan is the more extensive of the two programs. It requires groundwater monitoring and compliance with constituent-specific groundwater standards; prevention of compliance point exceedances; time constraints for initiating and completing cleanup; semi-annual reporting of program effectiveness; procedures to amend cleanup plans; and conditions for operating corrective action management units and temporary units. The scope of the EPA corrective action program can include both hazardous and solid waste management units on-site. An EPA permit application must address cleanup of both categories of waste management units.

**Table A-5. Corrective Action**

Topic	Authority	
	EPA	NRC
<b>Comply with groundwater protection standards</b>	RCRA groundwater standards (40 CFR 264.92) <i>40 CFR 264.100(a)</i>	GENERAL: The licensee must have plans for taking corrective measures if migration of radionuclides would indicate the performance objectives of Subpart C may not be met. <i>10 CFR 61.53(b)</i>
<b>Prevent exceedance of hazardous constituent concentration limits at compliance point (including groundwater)</b>	Remove or treat in place the hazardous waste constituents <i>40 CFR 264.100(c), (e)</i>	During construction and operation— <ul style="list-style-type: none"> <li>• Maintain a monitoring program . . . to enable . . . effects and need for mitigative measures</li> <li>• Monitoring system must provide early warning of releases of radionuclides from the disposal site before they leave the “site boundary” <i>10 CFR 61.53(c)</i></li> </ul> Every reasonable effort shall be made to maintain radiation exposures as low as is reasonable achievable <i>10 CFR 61.43</i>
<b>Time frame—Initiation</b>	Begin within reasonable period after groundwater protection standard is exceeded <i>40 CFR 264.100(c)</i>	
<b>Groundwater Monitoring</b>	Demonstrate effectiveness of corrective action program <i>40 CFR 264.100(d)</i>	
<b>Timeframe—Extent</b>	Continue corrective action measures as long as necessary to achieve the groundwater protection standard <i>40 CFR 264.100(f)</i>	
<b>Report effectiveness</b>	Semi-annually <i>40 CFR 264.100(h)</i>	
<b>Amend program if unsatisfactory</b>	Apply for permit application within 90 days of determination <i>40 CFR 264.100(i)</i>	

(continued)

**Table A-5. (continued)**

Topic	Authority	
	EPA	NRC
<b>Solid waste management units (SWMUs)</b>	All TSDFs seeking permits must institute corrective action for all releases of hazardous wastes or constituents from <u>any</u> SWMU at the facility regardless of time of placement <i>40 CFR 264.101</i>	
<b>Corrective Action Management Units and Temporary Units</b>	Operating and performance factors considered by EPA Regional Administrator <i>40 CFR 264.552, .553</i>	
<b>Permitting</b>	Part B application must contain <ul style="list-style-type: none"> <li>• An engineering feasibility plan for any corrective action (if hazardous constituent detected in groundwater at point of compliance at time of permit application) <i>40 CFR 264.14(c)(7)</i></li> <li>• Sufficient information to establish a corrective action program</li> <li>• Detailed plans and engineering report describing corrective action to be taken</li> <li>• A description how the groundwater monitoring program will demonstrate adequacy of the corrective action <i>40 CFR 270.14(c)(8)</i></li> </ul>	

**TABLE A-6. CLOSURE**

Closure requirements of the two authorities have a number of topics in common but each authority's requirements are unique. Highlights of these differences are expressed below.

EPA regulations require the Regional Administrator be notified 60 days before the date closure is expected to begin.

EPA-regulated HW facility closure plans must be approved by EPA's Regional Administrator.

EPA regulations require 30 years of post-closure care and for landfills post-closure care must continue beyond 30 years, if necessary, until leachate is no longer detected. If mixed waste is managed, it may be addressed in permit applications for the operation of contiguous disposal facilities.

NRC requires institutional controls by the land owner or custodial agency. These controls include, at a minimum, environmental monitoring, periodic surveillance, minor custodial care, and physical control of access to the disposal site.

Both EPA and NRC regulations contain procedures for renewing and/or amending permits/licenses that address closure activities.

EPA and NRC regulations also outline information requirements for closure plans. However, EPA regulations are more specific, containing unique information requirements for wastepiles, surface impoundments, and landfills. (NRC regulations do contain performance criteria for landfill closure that are similar to EPA-regulated landfills, including cover performance, erosion control, and keeping disposed waste dry.)

**Table A-6. Closure**

Topic	Authority	
	EPA	NRC
<b>Closure plan applicability</b>	All new and existing disposal facilities, Wastepiles, surface impoundments, tank systems (per 264.197), and containment buildings (per 264.1102) <i>40 CFR 264.110</i>	
<b>Closure timeframe</b>	<p>Notify 60 days before date expected to begin closure. Begin closure no later than 30 days after date of receipt of final waste volume <i>40 CFR 264.112(d)</i></p> <p>Complete treatment, removal, disposal within 90 days of receipt of final waste volume <i>40 CFR 264.113(a)</i></p> <p>Complete closure within 180 days of receipt of final waste volume <i>40 CFR 264.113(b)</i></p>	
<b>Review and approval authority for closure plan</b>	<p>EPA Regional Administrator <i>40 CFR 264.112(a)(1)</i></p> <p>Reference to “Director’s” approval <i>40 CFR 264.112(a)(2)</i></p>	
<b>Termination of monitoring and maintenance at closed facilities or sites</b>	<p>30 years post-closure care <i>40 CFR 264.117 (a)(1)</i></p> <p>For landfills, continue care until leachate no longer detected <i>40 CFR 264.310(b)(2)</i></p>	100 years institutional controls <i>10 CFR 61.59(b)</i>
<b>License/permit renewal/ amendment</b>	<p>Must submit written request for a permit modification to amend plan when—</p> <ul style="list-style-type: none"> <li>Changes in design or operation affect plan</li> </ul>	Failure to renew license shall not relieve licensee of closure/post-closure responsibilities. <i>10 CFR 61.27(a)</i>

(continued)

**Table A-6. (continued)**

Topic	Authority	
	EPA	NRC
	<ul style="list-style-type: none"> <li>Year of closure expected to change</li> <li>Unexpected events during closure require change</li> </ul> <p>40 CFR 264.112(c)(1)-(2)</p> <p>Submit request 60 days before change or no later than 60 days after unexpected event</p> <p>40 CFR 264.112(c)(3)</p> <p>Regional Administrator may request change</p> <p>40 CFR 264.112(c)(4)</p>	<p>Application for closure must be filed 30 days prior to license expiration</p> <p>10 CFR 61.27(a)</p> <p>Before final site closure, licensee must submit application to amend license for closure</p> <p>10 CFR 61.28</p>
<b>Content of plan (or AEA license amendment)</b>	<ul style="list-style-type: none"> <li>How each unit will be closed</li> <li>How final closure will be conducted to achieve performance standards</li> <li>Estimate of maximum inventory during active life and measures during closure to reduce inventory</li> <li>Steps to remove or decontaminate all residues and system components</li> <li>Other activities needed to ensure attainment of performance standards</li> <li>Schedule of closure for each unit on-site</li> <li>Estimated year of final closure</li> </ul> <p>40 CFR 264.112(b)</p>	<p>Geologic, hydrologic, or other disposal site data pertinent to longterm containment of radioactive waste during the operational period</p> <p>10 CFR 61.28(a)(1)</p> <p>Results of tests, experiments, and any other analysis relating to backfill of excavated areas, closure and sealing, waste migration and interaction with emplacement media, or any other tests pertinent to long-term containment of waste</p> <p>10 CFR 61.28(a)(2)</p> <p>Proposed plan revisions for decontamination/dismantlement of surface facilities, backfilling of excavated areas, or stabilization of disposal site for post-closure care</p> <p>10 CFR 61.28(a)(3)</p>

(continued)

**Table A-6. (continued)**

Topic	Authority	
	EPA	NRC
<b>Content of plan (or NRC license amendment) (continued)</b>	<p>Wastepiles without liners:</p> <ul style="list-style-type: none"> <li>Plans to (1) decontaminate site and (2) contingency measures if decontamination is incomplete</li> <li>Contingent post-closure plan</li> <li>Cost of contingent closure and post-closure care <i>40 CFR 264.258</i></li> </ul>	<p>Environmental report or supplement (in accordance with 10 CFR Subpart A of Part 51) must accompany application <i>10 CFR 61.28(b)</i></p>
<b>Conditions for approval</b>	<ul style="list-style-type: none"> <li>Closure minimizes need for further maintenance</li> <li>Controls, minimizes, or eliminates contaminants to extent to protect human health and environment</li> <li>Complies with respective waste management units' disposal requirements <i>40 CFR 264.11</i></li> </ul>	<p>Reasonable assurance that long-term performance objectives of 10 CFR 61 Subpart C will be met <i>10 CFR 61.28(c)</i></p>
<b>Closure specifications</b>	<p>Landfills:</p> <ul style="list-style-type: none"> <li>Cover achieves— <ul style="list-style-type: none"> <li>longterm minimization of liquid migration through landfill</li> <li>minimized maintenance</li> <li>promotion of drainage and minimizes erosion/abrasion</li> <li>Accommodates settling and subsidence</li> <li>Permeability <math>\leq</math> bottom liner or natural subsoil <i>40 CFR 264.310</i></li> </ul> </li> <li>Post-closure care, including monitoring and maintenance of: <ul style="list-style-type: none"> <li>final cover</li> <li>leachate collection and removal system</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>Minimize, to the extent practicable, water infiltration</li> <li>Direct percolating or surface water away from the disposed waste</li> <li>Resist degradation by surface geologic processes and biotic activity <i>10 CFR 61.51(a)(4)</i></li> </ul> <p>Surface features direct surface water drainage away from units at velocities and gradients to avoid erosion that requires ongoing active maintenance in the future <i>10 CFR 61.51(a)(5)</i></p>

(continued)

**Table A-6. (continued)**

Topic	Authority	
	EPA	NRC
<b>Closure specifications (continued)</b>	<ul style="list-style-type: none"> <li>- leachate detection system</li> <li>- groundwater monitoring system (per Subpart F)</li> <li>- Prevent damage from run-on and run-off</li> <li>- Protect/maintain surveyed benchmarks</li> </ul> <i>40 CFR 264.310</i>	<p>Minimize, to the extent practicable—</p> <ul style="list-style-type: none"> <li>• Contact with water during waste storage</li> <li>• Contact with standing water during disposal</li> <li>• Contact with standing or percolating water after disposal</li> </ul> <i>10 CFR 61.51(a)(6)</i>

**TABLE A-7. SITE PROPERTIES**

EPA and NRC regulations all address seismic conditions, flooding/runon, and erosion when siting facilities. However, only EPA regulations specify the Holocene era's faults in its seismic regulations. EPA regulations allow waste management in 100-year flood plains if suitable engineering and/or operating and contingency measures are in place. NRC prohibits any disposal in 100-year flood plains.

There are several cases where the two authorities share similar siting requirements. For example, EPA siting requirements consider the waste technology planned for the proposed site. Regulations specifically cite protection of groundwater, although groundwater considerations are also inherent in EPA siting. Wetlands, coastal high hazard areas, and proximity to natural resources are considered in some respect under at least two of the three authorities. Under EPA regulations, these topics are addressed in the performance standards for miscellaneous units (wetlands and wildlife) and in permitting regulations (The Coastal Zone Management Act, The Endangered Species Act, and the Fish and Wildlife Coordination Act). NRC regulations specifically ban disposal in wetlands and coastal high hazard areas.

**Table A-7. Site Properties**

Topic	Authority	
	EPA	NRC
<b>Adverse impact by nearby activities</b>		<i>10 CFR 61.50(a)(11)</i>
<b>Consider planned waste technology</b>	Land disposal design requirements <i>40 CFR 264</i>	
<b>Site capable of characterization, analysis, modeling, and monitoring</b>		<i>10 CFR 61.50(a)(2)</i>
<b>Protective of groundwater</b>	(See Disposal Unit Design Table 3) Groundwater protection standards for releases from SWMU's. Not to exceed concentration limits beyond compliance boundary <i>40 CFR 264.92</i>	<i>10 CFR 61.50(a)(8)</i>
<b>Prevent groundwater intrusion into waste unit</b>	(See Disposal Unit Design Table 3) Groundwater protection standards for releases from SWMU's. Not to exceed concentration limits beyond compliance boundary <i>40 CFR 264.92</i>	<i>10 CFR 61.50(a)(7)</i>
<b>Seismic conditions</b>	Not located within 200 feet of Holocene fault <i>40 CFR 264.18(a)</i>	Avoid areas where tectonic processes threaten performance objectives or preclude defensible modeling and prediction of long-term impacts <i>10 CFR 61.50(a)(9)</i>
<b>100 year flood plain</b>	Facility must be designed, constructed, operated and maintained to prevent washout of any hazardous waste unless demonstrated that (1) waste removed safely before flood or (2) for existing units, no adverse effects will result from washout <i>40 CFR 264.18(b)</i>	Banned from 100 year flood-plains <i>10 CFR 61.50(a)(5)</i>
<b>No bulk liquids in salt formations</b>	<i>40 CFR 264.18(c)</i>	
<b>Wetlands</b>	Environmental performance standards for miscellaneous units. Prevention of adverse effects <i>40 CFR 264.601(b)</i>	Banned from wetlands <i>10 CFR 61.50(a)(5)</i>

(continued)

**Table A-7. (continued)**

Topic	Authority	
	EPA	NRC
<b>Coastal high hazard areas</b>	Compliance with Coastal Zone Management Act, where applicable, falls within RCRA permit <i>40 CFR 270.3(d)</i>	Banned from coastal high hazard areas <i>10 CFR 61.50(a)(5)</i>
<b>Erosion</b>	Flood plain engineering measures <i>40 CFR 264.18(b)</i>	Avoid areas where erosion threatens performance and precludes defensible prediction of long-term impacts <i>10 CFR 61.50(a)(10)</i>
<b>Proximity to populations/development</b>		Avoid areas that may threaten meeting compliance objectives <i>10 CFR 61.50(a)(3)</i>
<b>Proximity to natural resources</b>	Environmental performance standards for miscellaneous units: Prevention of adverse effects considering wildlife <i>40 CFR 264.601(a)(9); (b)(11)</i>  Compliance with the Wild and Scenic Rivers Act and the Endangered Species Act, where applicable, fall within RCRA permit <i>40 CFR 270.3(a) and (c), resp.</i>	Avoid areas that may threaten meeting compliance objectives <i>10 CFR 61.50(a)(4)</i>
<b>Prevent runoff</b>	Flood plain engineering measures <i>40 CFR 264.18(b)</i>	Minimize upstream drainage <i>10 CFR 61.50(a)(6)</i>

**TABLE A-8. PERFORMANCE**

Protection of public health and safety at disposal sites is a common performance goal for EPA and NRC regulations. For EPA hazardous waste landfills, performance is technology-based as exemplified by the land disposal restrictions. As with EPA, NRC regulations attain these performance objectives through siting, design, operation, closure, and post-closure control. NRC regulations further state that “reasonable” efforts should be made to assure compliance with exposure limits and to keep exposure during operation ALARA.

As mentioned above, NRC regulations contain numeric exposure limits as their performance objectives. These exposure limits are established for external exposure to radioactive waste and material via releases from disposal sites to air, surface water, groundwater, soil, plants, and animals. These limits are expressed in terms of continuous exposure and single acute exposure.

Performance assessments during the active life of facilities are identified in the two authorities. Under EPA regulations, (1) action leakage rates represent performance assessments of wastepiles and landfills; (2) groundwater concentration limits of hazardous constituents are specified in EPA hazardous waste permits; and (3) detection and compliance monitoring programs track land disposal units’ performance. NRC requires an assessment of a disposal site’s performance from the perspective of post-closure stability, eliminating (to the extent practicable) the need for ongoing active maintenance after closure.

**Table A-8. Performance**

Topic	Authority	
	EPA	NRC
<b>Protect public health and safety for disposal sites</b>	Technology-based land disposal restrictions generally believed to be protective of human health and the environment <i>40 CFR 268 (51 FR 0578)</i>	Siting design, operation, closing and post-closure control must provide reasonable assurance that exposures are within limits of 10 CFR 61.41-61.44. During operation, reasonable efforts to maintain ALARA. <i>10 CFR 61.43.</i>
<b>External exposure to waste and radioactive active material via releases to surface water, groundwater, soil, plants, and animals for disposal sites</b>		Whole body: $\leq 25$ mrem/yr Thyroid: $\leq 75$ mrem/yr Any other organ: $\leq 25$ mrem/yr <i>10 CFR 61.41</i>
<b>External exposure to waste and radioactive material via release to atmosphere for disposal sites</b>		Whole body: $\leq 25$ mrem/yr Thyroid: $\leq 75$ mrem/yr Any other organ: $\leq 25$ mrem/yr <i>10 CFR 61.41</i>
<b>Releases of radioactive materials in effluents to the general environment for disposal sites</b>		ALARA <i>10 CFR 61.41</i>
<b>In advertent exposure due to intrusion onto facility and loss of active institutional control after 100 years for disposal sites</b>		Design, operation, and closure to ensure protection of inadvertent intruder <i>10 CFR 61.42</i>
<b>Protect groundwater for disposal sites</b>	Technology-based land disposal restrictions generally believed to be protective of human health and the environment <i>40 CFR 268 (51 FR 0578)</i>	
<b>Performance Assessments</b>	<ul style="list-style-type: none"> <li>Action leakage rate designated per unit <i>40 CFR 264.222, .252, and .302</i></li> <li>Groundwater concentration limits of hazardous constituents specified in permit <i>40 CFR 264.94</i></li> <li>Detection and compliance monitoring program <i>40 CFR 264.98 and .99</i></li> </ul>	
		(continued)

**Table A-8. (continued)**

Topic	Authority	
	EPA	NRC
<b>Assess performance of disposal site during post-closure</b>	<p>For 30 years:</p> <ul style="list-style-type: none"> <li>• Operate leachate collection system until leachate is no longer detected <i>40 CFR 264.310(b)(2)</i></li> <li>• Monitor groundwater monitoring system and comply with respective requirements <i>40 CFR 264.310(b)(4)</i></li> </ul>	<p>Site, design, use, operate and close facility to achieve longterm stability and eliminate the need for ongoing active maintenance after closure so that only surveillance, monitoring, or minor custodial care are required <i>10 CFR 61.44</i></p>